Handbook of Pragmatics Highlights 3

Cognition and Pragmatics

Edited by Dominiek Sandra,
Jan-Ola Östman
and Jef Verschueren

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Handbook of Pragmatics Highlights (HoPH)

The ten volumes of *Handbook of Pragmatics Highlights* focus on the most salient topics in the field of pragmatics, thus dividing its wide interdisciplinary spectrum in a transparent and manageable way. Each volume starts with an up-to-date overview of its field of interest and brings together some 12–20 entries on its most pertinent aspects.
Since 1995 the *Handbook of Pragmatics (HoP)* and the *HoP Online* (in conjunction with the *Bibliography of Pragmatics Online*) have provided continuously updated state-of-the-art information for students and researchers interested in the science of language in use. Their value as a basic reference tool is now enhanced with the publication of a topically organized series of paperbacks presenting *HoP Highlights*. Whether your interests are predominantly philosophical, cognitive, grammatical, social, cultural, variational, interactional, or discursive, the *HoP Highlights* volumes make sure you always have the most relevant encyclopedic articles at your fingertips.

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Volume 3

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Table of contents

Preface to the series

In 1995, the first installments of the **Handbook of Pragmatics (HoP)** were published. The HoP was to be one of the major tools of the International Pragmatics Association (IPrA) to achieve its goals (i) of disseminating knowledge about pragmatic aspects of language, (ii) of stimulating various fields of application by making this knowledge accessible to an interdisciplinary community of scholars approaching the same general subject area from different points of view and with different methodologies, and (iii) of finding, in the process, a significant degree of theoretical coherence.

The HoP approaches pragmatics as the cognitive, social, and cultural science of language and communication. Its ambition is to provide a practical and theoretical tool for achieving coherence in the discipline, for achieving cross-disciplinary intelligibility in a necessarily diversified field of scholarship. It was therefore designed to provide easy access for scholars with widely divergent backgrounds but with converging interests in the use and functioning of language, in the topics, traditions, and methods which, together, make up the broadly conceived field of pragmatics. As it was also meant to provide a state-of-the-art report, a flexible publishing format was needed. This is why the print version took the form of a background manual followed by annual loose-leaf installments, enabling the creation of a continuously updatable and expandable reference work. The flexibility of this format vastly increased with the introduction of an online version, the **Handbook of Pragmatics *Online*** (see www.benjamins.com/online).

While the HoP and the HoP-online continue to provide state-of–the-art information for students and researchers interested in the science of language use, this new series of **Handbook of Pragmatics *Highlights*** focuses on the most salient topics in the field of pragmatics, thus dividing its wide interdisciplinary spectrum in a transparent and manageable way. The series contains a total of ten volumes around the following themes:

- Key notions for pragmatics
- Pragmatics, philosophy and logic
- Grammar, meaning and pragmatics
- Cognition and pragmatics
- Society and language use
- Culture and language use
- The pragmatics of variation and change
- The pragmatics of interaction
- Discursive pragmatics
- Pragmatics in practice

This topically organized series of paperbacks, each starting with an up-to-date overview of its field of interest, each brings together some 12-20 of the most pertinent HoP entries. They are intended to make sure that students and researchers alike, whether their interests are predominantly philosophical, cognitive, grammatical, social, cultural, variational, interactional, or discursive, can always have the most relevant encyclopedic articles at their fingertips. Affordability, topical organization and selectivity also turn these books into practical teaching tools which can be used as reading materials for a wide range of pragmatics-related linguistics courses.

With this endeavor, we hope to make a further contribution to the goals underlying the HoP project when it was first conceived in the early 1990's.

Jan-Ola Östman (University of Helsinki) &
Jef Verschueren (University of Antwerp)

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A project of the HoP type cannot be successfully started, let alone completed, without the help of dozens, even hundreds of scholars. First of all, there are the authors themselves, who sometimes had to work under extreme conditions of time pressure. Further, most members of the IPrA Consultation Board have occasionally, and some repeatedly, been called upon to review contributions. Innumerable additional scholars were thanked in the initial versions of handbook entries. All this makes the Handbook of Pragmatics a truly joint endeavor by the pragmatics community world-wide. We are greatly indebted to you all.

We do want to specifically mention the important contributions over the years of three scholars: the co-editors of the Manual and the first eight annual installments, Jan Blommaert and Chris Bulcaen were central to the realization of the project, and so was our editorial collaborator over the last four years, Eline Versluys. Our sincerest thanks to all of them.

The Handbook of Pragmatics project is being carried out in the framework of the research program of the IPrA Research Center / Antwerp Center for Pragmatics at the University of Antwerp. We are indebted to the university for providing an environment that facilitates and nurtures our work.

Jan-Ola Östman (University of Helsinki) &
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Perspectives on language and cognition

From empiricism to rationalism and back again

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1. Language and cognition: Defining aspects of human nature

'Language' and 'cognition', the two words from the title of the present volume, could both be used to characterize human beings. To the best of our knowledge, we are the only creatures on this planet to make use of a communication system meeting the complexity of natural languages. All research that has been done in the sixties and seventies of the previous century to assess the language capacity of chimpanzees converges on the conclusion that these animals can learn some 100 to 150 words but that they never achieve the level where they realize the symbolic status of these words. Words are not mere members in an associate pairing with the thing they refer to, but represent the concept behind these referents in some code system (e.g., speech, signs, …). Nor did the animals succeed in constructing word strings in accordance with syntactic rules. Both symbolic behavior (Deacon 1997) and syntactic capacity (Chomsky 1965), which some researchers consider as a particular manifestation of symbolic representation at a higher organizational level (Deacon 1997; Langacker 1990; this volume), characterize human language. Hence, despite the many capabilities of great apes, they lack the capacity for natural language. In a *Science* paper thirty years ago, Herb Terrace and his colleagues critically analysed researchers' attempts to teach great apes to make use of language and concluded that they dismally fail when judged against the critical dimensions that define natural languages: "Apes can learn many isolated symbols (as can dogs, horses, and other nonhuman species), but they show no unequivocal evidence of mastering the conversational, semantic, or syntactic organization of language." (Terrace, Petitto, Sanders, & Bever 1979: 902). Today, no evidence has appeared to suggest that this conclusion needs to be changed.

Similarly, we seem to be the only species on earth that has the ability to use higher-order cognitive functions. Michael Tomasello from the Max Planck Institute for Evolutionary Anthropology in Leipzig has done highly original work on chimpanzee intelligence. Thus far, the conclusion of this research programme is that these animals are a lot smarter than one might imagine, and in some respects even possess a theory of mind, i.e., the capacity to know what another member of their species knows (Call & Tomasello 2008). However, another conclusion is that their cognitive abilities fall far short of the cognitive skills that humans possess. In experiments probing chimpanzees' capacity to take advantage of their knowledge of what another ape knows, the animals perform less well than six-year old children (Kaminski, Call, & Tomasello 2008). In an experiment where two chimpanzees are facing each other and the experimenter puts one piece of low-quality food and one piece of high-quality food under two of three opaque buckets, the experimental ape (subject) had to choose after the other chimpanzee (competitor) had lifted a bucket. Crucially, the subject could not see which choice his competitor had made. In such a difficult choice situation, the only way to optimalize one's chances for retrieving the high-quality food is by relying on one's knowledge of the competitor's knowledge (i.e., had the competitor seen the experimenter hide the food?). In one context the subject witnessed the hiding of both pieces of food, whereas the competitor only saw the experimenter hide the low-quality food. In such a situation the subject more often chose the bucket where he knew the high-quality food to be and also knew the competitor did not share this knowledge, compared to a situation where both chimps had seen the hiding of the two pieces of food and, hence, the subject knew that the competitor also knew the place of the high-quality food. It follows that chimps are able to act on the basis of their knowledge of another chimp's knowledge, which is quite an accomplishment.

However, in the same experiment the subject could not take advantage of the fact that his competitor was 'deceived' by the experimenter and, hence, acted on the wrong knowledge (a false belief). In this experiment the experimenter hid both pieces of food while both the subject and the competitor were watching, but afterwards made one of two manipulations that only the subject could see. Either he lifted the bucket under which the high-quality food was hidden and put it down again (i.e., changed nothing) or he placed the food under another bucket. The subject did not choose for the high-quality food more often under the latter circumstances, although he should have done so if he had realized that the competitor could not possibly know about the new location of the food and should have made his choice on a false belief. This demonstrates that chimpanzees cannot distinguish between a condition in which the competitor has the correct belief about where the best food is hidden and one in which he has a false belief. Importantly, in the same experiment, six-year old children did make this distinction, demonstrating that, at such a young age already, their cognitive skills surpassed those of chimpanzees: they realized when their competitor had to act on a false belief, chimps did not. This is why Call and Tomasello (2008) argue that in some respects chimpanzees display the properties of a theory of mind (they know what competitors know) but in other respects they do not (they do not know when competitors will act on a false belief).

The fact that both the intricacies of natural language and the ability to use high-level cognitive skills seem to be the province of human beings only, may suggest that these two typically human capacities are closely intertwined and that one can only exist by virtue of the opportunities offered by the other (mutual dependence). So, when looking at what separates us from our closest ancestors, the hypothesis that naturally comes to mind is that language and higher cognition are likely to be two sides of a single coin. Whereas the majority of contributions to this volume take this for granted, this has not always been the case.

2. Language without mind: Structuralism and behaviorism

Sixty years ago a collection of papers on the relationship between language and cognition would have been unthinkable. When the first half of the twentieth century came to an end, researchers on language, both linguists and psychologists, simply did not address cognitive issues. The positivist methodology that had produced so many big successes in the 'hard' sciences had also been adopted by entirely different scientific disciplines, like linguistics and psychology. The research credo of the day was: Stick to the facts, make an inventory of the observable phenomena and describe them as accurately as you can, using well-defined methods.

Thus, in the context of the study of language, linguists applied procedures for discovering the basic building blocks of a language, i.e., the units that defined its structure, which naturally gave them the name 'structuralists'. Psychologists studying language use also restricted themselves to the observable facts and linked them to the basic concepts of classical learning theory: a stimulus (e.g., seeing a chair) causes someone to produce a language response (the spoken word *chair*), a response that will be made again on a following occasion when it is reinforced in one way or another. Similarly, associative links emerge between two words as a result of their co-occurrence frequency in sentences. Hence, language learning was considered to be a matter of learning to make associations, on the one hand between external stimuli and words, and on the other hand between pairs of words, which provided the raw material for constructing longer associative chains, namely sentences. Thus psychologists reduced the investigation of language use to the study of speakers' observable language behavior (which gave them the name 'behaviorists'): making associations on the basis of operant conditioning. This view culminated in Harvard's B.F. Skinner's book *Verbal Behavior* (1957).

In other words, in the first half of the 20th century, whatever needed to be said about language or its use was 'out there', right in front of the linguist's or psychologist's eyes. Researchers axiomatically believed that the systematicities or laws that they had to discover should not make reference to mental phenomena, invisible 'ghosts' in the human mind whose task would be to act as crucial mediators in the process of stimulus-response association. Note that the point is not so much that behaviorists denied the existence of cognitive structures and processes, rather that they rejected them as objects of scientific study, for the simple reason that they were not accessible to direct observation. By doing so, they reduced language to a purely mechanistic phenomenon, as if it were a piece of machinery stringing one word to the other on the basis of learnt associations in the past of the individual speaker. Note that this metaphor fits the mathematical implementation of behaviorist thinking: the finite-state automaton. Such an automaton starts in a particular state S_0 (word 1), switches to state S_1 by following an associative link in its architecture (word 2), and so on, until a string of words has been concatenated.

It is somewhat strange, that even while adopting the positivist methodology of their fellow researchers in the exact sciences, behaviorists seem to have applied it even more rigourously than their colleagues. Restricting oneself to the raw facts does not imply that one cannot advance hypotheses on non-observable phenomena. As a matter of fact, unless a scientific discipline wants to accept that its job is finished once the phenomenon under study has been adequately described, any explanation of this phenomenon necessarily implies the postulation of abstract constructs, which are, by definition, not observable (if they were, there would be no need for scientific inquiry in the first place!). As a case in point, take gravity. Gravity itself is not observable, only its effects on objects are. The same applies to all other basic forces in nature and many entities that figure prominently in physics: the electro-magnetic force, the weak and strong nuclear forces, a quantum of energy, gravitons, the big bang, the acceleration of the universe, etc. All of these have been inferred from careful observations but cannot be directly observed (or could not be at the time of their discovery). Still, these non-observable entitites form the very cornerstones of theories in physics and scientists have set themselves the task of making exact measurements of them or devising experiments in which they can see the effects of the hypothesised entities. Already in the 17th century Newton determined the value of the gravitational constant: on Earth a mass of 1 kg falls at a speed of 9.81 m/s^2 at sea level.

So, unlike what is often believed, behaviorists did not simply step into the footprints of their colleagues in the beta sciences. Unlike their fellow scientists they refused to go further than the observable facts. Hence, it seems that the major difference between the explanatory concepts in, for instance, physics and psychology, is not so much the fact that these constructs cannot be directly observed in psychology – the notion of a 'non-observable explanatory construct' is tautological – but rather that physical constructs exist in the physical world and relate physical observations to each other, whereas psychological constructs exist in a different, (i.e., mental) world, whereas they also relate physical observations to each other. Postulating mental events as explanatory concepts for observable facts seems to be a subscription to a theory that adheres to dualism. This is an undesirable position, as nobody knows how mental and physical events can ever make contact with each other. Accordingly, the best one can do as a scientist is to ban all references to the mental world from one's theory, on the grounds that scientific concepts must be verifiable.

Or so it would seem at first sight, because mental phenomena are ultimately encoded in brain matter, which is also a physical entity, so that mental representations and processes need not (and do not) have a metaphysical status at all, and hence should not be banished from scientific discourse. Cognitive concepts merely offer a comprehensive vocabulary for talking about stored knowledge and processes operating on this knowledge, both of which are encoded in the biological and biochemical structure of neural tissue. They merely offer a useful terminological interface between the neural architecture underpinning language, which somehow encodes the cognitive constructs, and the observable and measurable language phenomena. Not a single scientific reason can be found why cognition should ever have been banned from research on language.

3. Language and mind: The mentalist era

There may have been multiple reasons why behaviorists eschewed mentalist statements and were hard-core empiricists, but even independently of the above discussion about the nature of scientific explanation, their theory about language was plainly wrong. The man who demonstrated that quite convincingly was Noam Chomsky, who published a review in *Language* (Chomsky 1959) in which he fiercely attacked Skinner's book *Verbal Behavior.* In Chomsky's view Skinner's theory epitomized the behaviorist programme. By demonstrating that his ideas about language represented human language use as a finite-state automaton and showing that this type of formal grammar cannot possibly capture the complexity of human languages, he crushed behaviorism with a single blow. This blow marked a paradigm shift in linguistics (Chomsky 1965), whose consequences have left their fingerprints on many subdisciplines today, even though many linguists and psychologists of language abandoned Chomsky's ideas a long time ago. When he entered the scene, researchers' perspective on the nature of language radically changed. An era of exteme empiricism was over and was soon to be replaced by a new period of extreme rationalism.

Chomsky's main revolutionary idea was the opposite of the deeply entrenched empiricism in behaviorist thinking. In his view, language had to be approached from a mentalist perspective. Indeed, his major tenet was that the essence of language was a mental 'organ', the analog to a bodily organ like the heart, whose structure is genetically hard-wired and, in this case, species-specific. An adequate description of the structure of individual human languages, he argued, was just the first step towards what should be the major goal of linguistics: explanatory adequacy. Like any other science, linguistics should not only collect and taxonomize the linguistic data, it should also explain them. More specifically, it should identify an abstract model of Language (not a language) that could explain why human languages are structured the way they are. This model would determine the nature of a language user's competence, i.e., his implicit knowledge of his native language, and would have nothing to do with what Chomsky called performance: the actual use of language.

As Chomsky had been brought up in the structuralist tradition his natural focus was on syntactic patterns. He hypothesized that, throughout the diversity of human languages, some of these patterns would recur (perhaps in the same way that many biological aspects recur across the animal kingdom) and would thus be universal properties of Language. This line of reasoning was compatible with his conviction that many of the syntactic principles in natural languages are so abstract that children could not possibly discover them so rapidly in the course of language acquisition. The language data children are confronted with, he argued, are so underspecified that they allow too many possible abstractions, i.e., representations of the grammar behind the child's language exposure. Taken together, the hypotheses that natural languages should display recurring syntactic patterns and that children cannot learn many important syntactic principles of their language, converged in a single proposal: there must be a Universal Grammar. According to this idea, human beings are genetically predisposed to make use of natural languages, not because they rely on general principles of higher-order cognition but because they share a set of abstract principles that together constrain the form any human language can take. This point of view, already clearly articulated in his 1965 book, was as anti-behaviorist as possible. The true nature of language is not to be found in the observable data but in the human mind and can be described as a set of abstract, syntactic principles that guide the young child through the chaos of language inputs it is exposed to and thus help it find orderly patterns.

As mentioned above, despite the strong mentalist nature of Chomsky's research programme, it did not derive language from the application of general cognitive principles. Quite on the contrary, in Chomsky's view, Universal Grammar was a given, not a derivative of higher cognition. In all his books he emphasized that human beings' language capacity instantiated a separate mental faculty, which was both species-specific and goal-specific, i.e, fully dedicated to the task of language acquisition and worthless for anything else. It was a separate module in the mind that functioned completely autonomously. This idea of modularity would later inspire the philosopher Jerry Fodor to write his book *Modularity of Mind* (1983).

Irrespective of the truth of Chomsky's hypothesis about the existence of a Universal Grammar, any historically fair approach to the evolution in linguistic thinking should give him credit for having had a brilliant idea at the time. The search for a Universal Grammar may turn out to have been a misguided research programme (also bear in mind that one can only discount a theory after years of careful study), but it was certainly a scientifically valid one. As a matter of fact, his logic was the same as the reasoning that so many scientists, in various discipines, had followed before him: look for a constant pattern in the variability of the data. This constant pattern will unify the observations and ultimately lead to an explanatory theory of the phenomenon under study. It was the same kind of rationale that Gregor Mendel followed when he discovered the laws governing the way certain biological traits are inherited: first carefully study a trait in several generations of a species, then look for patterns and, finally attempt to identify abstract laws that give rise to these patterns.

Nor was Chomsky's idea of separating competence from performance any different from common practice in other sciences. Let us again make an analogy with physics. For instance, when dropping a feather and a stone from a height of, say, 200 metres, one will observe that the stone always reaches the ground first. That is self-evident: the stone is heavier. Wrong! Such small differences in mass have nothing to do with it. As we have all learnt at school, the difference is due to the effect of air friction. All objects are attracted to another body (here: the Earth) with a constant force, Newton's gravitational constant. As long as their masses do not differ by a large factor of magnitude, they will fall equally fast. However, due to the interaction of gravity and air friction, the feather is slowed down during its fall. One of the demonstrations of the astronauts on the Apollo 15 mission, during one of their walks on the Moon, was to show that when this interaction effect between gravity and air friction is removed (there is no air on the Moon) a hammer and a feather fell equally fast. Both objects hit the Moon surface at the same time when being dropped simultaneously from the same height. Now, Chomsky's argument that competence should be dealt with separately from performance is moulded on exactly the same logic. Human speech performance is competence in interaction with many other factors (working memory, attentional factors, …), so that this interaction necessarily obscures one's view of the underlying competence. Since Chomsky defined the true nature of language as the language user's competence, which itself was the product of another interaction – that between language exposure and the constraints imposed by Universal Grammar – he tended to discount performance as theoretically uninteresting, being contaminated by a host of noise factors.

The above is, of course, obviously true from Chomsky's own perspective, but it is only really true on two conditions: that there is indeed a Universal Grammar driving the language acquisition process and that the true nature of language is indeed this language-specific mental faculty, rather than, for instance, the communicative interactions that take place in a million places every minute of each day. What if performance were the true nature of language? In other words: Chomsky's reasoning was scientifically quite solid and admirable … provided that his initial premise, i.e., that a Universal Grammar exists and that the major task of linguistics is to identify its internal structure, was correct.

4. Language and cognition: A twin pair

Chomsky set himself an ambitious research programme: identify the abstract constraints on the grammar of human languages through the study of existing language patterns, which is like studying mental principles without doing any experiment (at various places in his books he indeed called linguistics a form of theoretical psychology). At the same time, his research focus fuelled novel research efforts. The study of language acquisition became crucially important, as the Chomskyan framework predicted that evidence should be found that important structural constraints in grammar are not acquired through a process of induction but rather on the basis of 'projecting' innate principles on the language input. Also the study of typologically different languages became a fascinating field of study. If Chomsky was right, one should be able to identify recurring syntactic principles in a variety of languages across the world, whether they belonged to the same typological family or not.

Not surprisingly, the theory also attracted the attention of experimental psychologists. Their motivation, however, derived from the more technical aspects of the theory. They were not interested in performing experiments that tested the existence of Universal Grammar (it is hard to imagine how such a goal could be accomplished through experimentation) but were attracted by what (in hindsight, somewhat misleadingly) announced itself as an essential ingredient of the Chomskyan programme: transformations. These were the technical tools that were responsible for transforming a so-called deep structure, which syntactically represented the meaning of the sentence (and, hence, could be mechanistically interpreted by a semantic component), into a surface structure, which syntactically represented the sentence's actual appearance (and, hence, could be mechanistically interpreted by a phonological component). One should not ignore the possibility that the name of the new paradigm, *Transformational Generative Grammar,* may have diverted some researchers' attention from the essential target of the theory – the identification of Universal Grammar – and may have overemphasized the technical aspects of the theory. The goal of sentence generation and the use of transformations to change one type of syntactic structure into another were nothing more than tools in an attempt to identify the correct formal grammar that could exhaustively characterize the possible sentences in a human language. Later developments of the theory would indeed indicate that transformations were only a (temporary) tool to implement the theory, a technicality rather than its essence.

However, a device that could generate sentences through the application of transformations had a natural appeal to experimental psychologists, as this created the impression that the theory was also about how sentences were generated in online speech production, i.e., a processing theory. Chomsky himself never intended his theory in this way, as his focus was on competence rather than performance and the dynamics of speech production is part of a performance theory, which fell outside his domain of interest. The following citation testifies to his position:

> To avoid what has been a continuing misunderstanding, it is perhaps worthwhile to reiterate that a generative grammar is not a model for a speaker or hearer. […] When we say that a sentence has a certain derivation with respect to a particular generative grammar, we say nothing about how the speaker or hearer might proceed, in some practical or efficient manner, to construct such a derivation. These questions belong to the theory of language use – to the theory of performance. (Chomsky 1965: p. 9)

Despite such warnings, transformations continued to be misinterpreted as a formal analogue to mental processes. That, in combination with the potentially misleading name of the new theory that was conquering the field of linguistics, soon gave rise to discussions about the *psychological reality* of the theory. Obviously, when the status of psychological reality is at issue, experimental psychologists are ideally placed to design the right kind of experiment for testing this hypothesis. Soon they started to design experiments in which they assessed, for instance, whether there was an analogy between the number of transformations that are needed to turn a deep structure into a surface structure and language users' processing time in an experimental task. This is referred to as the Theory of Derivational Complexity. George Miller (1962) found that, indeed, more transformations delayed responses in a timed language task. However, Fodor and Garrett (1966, 1967) soon rejected the idea that the technical framework of Chomskyan grammar mapped onto the complexity of language processing. For instance, even though phrases with a prenominal modifier as *the red book* should take more processing time according to transformational grammar than *the book that is red,* this was not confirmed by reaction time experiments.

By the mid-seventies, little evidence attesting to the theory's psychological reality had been assembled and little hope remained that a correspondence between Chomsky's theory and language users' processing complexity would ever be discovered. At that time, two important publications came out, in which the psycholinguistic attempts to assess the psychological reality of generative grammar were summarized: *The Psychology of Language* (Fodor, Bever, & Garrett 1974) and *Experimental Psycholinguistics* (Johnson-Laird 1974; for a critical review at a more distant point in time, see Tanenhaus 1988). For psycholinguists the time had come to define their own research agenda rather than testing the validity of linguistic theories. As Carlson and Tanenhaus (1982) claimed, the idea that linguists devised theories and that psycholinguists should then test the psychological valididy of such theories was the wrong way to go:

> The field [of psycholinguistics] has occasionally labored under the illusion that psycholinguistic evidence has some special properties which can decree the validity of given linguistic theories or analyses. But this is, quite simply, the wrong level of comparison. (p. 57)

So, the divorce between linguistics and psycholinguistics wasn't a bad thing because, if anything, the Chomskyan theory explicitly announced itself as a theory that did not address performance issues whereas psycholinguistic studies thus far had done nothing else but treating generative grammar as a processing theory. In other words, they had done nothing more than attacking a straw man. After a decade of experimentation, psycholinguists decided to focus on processing questions that were interesting outside the domain of linguistic theories and took a different road than linguists.

In the meantime, the initial homogeneity in the linguistic world itself had disappeared as well. Under the impetus of George Lakoff, amongst others, an alternative approach to generative grammar was proposed, generative semantics, which put semantics at the core of the linguistic model rather than syntax. This gave rise to fierce controversies among linguists in the early seventies, resulting in what has come to be kwown as the *linguistic wars,* which became the title of a 1993 book by Randy Harris.

Due to space limitations we cannot review all the evidence that caused cracks in Chomsky's orginal idea but, as years went by, all possible strands of potential evidence in favour of the theory failed to support it. For instance, the theory's core concept of a Universal Grammar predicts the existence of recurrent syntactic patterns across the many languages of the world. However, this could not be empirically confirmed. On the contrary, although the idea itself may have been an exciting one, the evidence seems to point in the direction that it has been a chimera nonetheless. In a very recent review paper in the authoritative journal *Behavioral and Brain Sciences,* Evans and Levinson (2009) advance the thesis that "there are vanishingly few universals of language in the direct sense that all languages exhibit them. […] decades of cross-linguistic work by typologists and descriptive linguists, showing just how few and unprofound the universal characteristics of language are, once we honestly confront the diversity offered to us by the world's 6–8000 languages." One of their conclusions, after carefully reviewing the evidence, is that "The diversity of language is, from a biological point of view, its most remarkable property – there is no other animal whose communication system varies both in form and content. It presupposes an extraordinary plasticity and powerful learning abilities able to cope with variation at every level of the language system. This has to be the central explicandum for a theory of human communication." So, it seems that what should, according to Chomsky, constitute one of the ultimate proofs that his theory was correct, i.e., the notion of a common structural matrix for languages across the world, ironically seems to lead to the conclusion that what is essential in language is diversity and what is essential about the human mind, whose task it is to deal with this diversity, is its high degree of plasticity (note that this is the opposite of rigid universal principles) and its powerful learning mechanisms (which runs against the idea of a modular, language-specific acquisition process).

As a matter of fact, this conclusion with respect to the existence of powerful learning mechanisms converges nicely with the insights that several language acquisition researchers have assembled over the last decade. Recall that language acquisition was the other domain where Chomsky had predicted to find corroborating empirical evidence for his theoretical analyses of the nature of language. However, there have been several indications in experimental work on this issue that children rely more often on their power of induction than would be expected on the basis of Chomsky's hypothesis that (i) there is a Universal Grammar and that (ii) children should approach their ambient language with implicit preconceptions about the structure of human language.

In a seminal paper Saffran, Aslin, and Newport (1996) discovered that when a set of four three-syllable nonwords (e.g., *tupiro, golabu, bidaku,* and *padoti*) were played randomly in a continuous manner, without any pauses or prosodic information that could signal boundaries between these new 'words', infants as young as eight months could discriminate trained from untrained words, even though they had been listening to the tape for only two minutes. They obtained these results, irrespective of whether the unfamiliar words were concatenations of three syllables that had never co-occurred on the tape (*dapiku*, i.e., no two syllables ever co-occurrred) or, more difficult, concatenations of a familiar word's final syllable and another familiar word's initial two syllables (*kupado,* i.e., the last two syllables co-occurred in a trained 'word'). The only information that the infants could rely on to discover constant units (words) in the input were the transitional probabilities between successive syllables, i.e., statistical regularities in the distribution of the syllables in the input. Only when three syllables always co-occurred in the training phase did they define a word. The authors conclude: "Our results raise the intriguing possibility that infants possess experience-dependent mechanisms that may be powerful enough to support not only word segmentation but also the acquisition of other aspects of language. It remains unclear whether the statistical learning we observed is indicative of a mechanism specific to language acquisition or of a general learning mechanism applicable to a broad range of distributional analyses of environmental input." (p. 1928).

Saffran (2001) found the same pattern of results when the familiar words were embedded in English sentences and recently Pelucchi, Hay, and Saffran (2009) found again the same pattern when eight month-old infants were exposed to words in a natural language that was not their native language, more particularly, Italian, extending the ecological validity of their earlier findings.

Perhaps even more strikingly Saffran, Hauser, Seibel, Kapfhamer, Tsao, and Cushman (2008) extended these results to the domain of grammatical pattern learning and found that infants who had been trained on predictable sequences of word types (on the basis of a very small set of rewriting rules and nonwords) were better in discriminating (repeated) grammatical from ungrammatical sentences than infants whose training materials did not contain predictable relations among word categories. The authors draw an important conclusion: "Our findings are consistent with the hypothesis that natural languages have been sculpted by potentially quite general human learning mechanisms: patterns that afford optimal learnability are most likely to predominate in the languages of the world" (p. 498). In other words: the patterns that do occur in several languages in the world (but see above to relativize this statement) do not reflect the existence of a Universal Grammar but the nature of general human learning mechanisms, which can detect some patterns more easily than others and, hence, mould languages according to their own properties. This is exactly the opposite of Chomsky's claim regarding the existence of hard-wired syntactic principles and a claim favouring the phylogenetic development of languages that is in line with the inductive powers of the human mind.

Seidenberg, MacDonald, and Saffran (2002) arrive at a similar conclusion. They raise the question: "Does grammar start where statistics stop?" and weigh the evidence pro and con in a balanced way, without arriving at a definite answer. However, their concluding sentence is that "the structure of language may have resulted in part from constraints imposed by the limits of human learning." (p. 554) This claim is based on the observation that many languages share similar structural constraints and display statistical regularities at different levels, which opens the possibility that general cognitive principles that are good at discovering such regularities have shaped the form of the world's languages. Again, the concept of a Universal Grammar is far away.

Obviously, not all researchers subscribe to this empiricist position and argue against points of view that attribute too much power to induction (Marcus & Berent 2003). Also the arguments made by Pinker, who eloquently popularised the Chomskyian position in his book *The Language Instinct* (although disagreeing with him on a number of issues) were systematically deconstructed by Geoffrey Sampson in *The 'Language Instinct' Debate* (2005). Tomasello (1995) rejected the very title of Pinker's book, and, hence, demolished his whole theory of language, in a paper with the unambiguous title "Language is not an instinct". And the debate has far from ended, as the titles of some papers highlight: "Universal Grammar, statistics or both?" (Yang 2004).

5. The contents of this volume

This book represents a broad array of approaches to language from a cognitive perspective. In the majority of these approaches, language and cognition are considered to be interacting capacities of the human mind, such that cognitive abilities do not play a peripheral but rather a crucial role in various forms of language use. The contributions have been ordered alphabetically, but in the following paragaphs I briefly review them thematically.

First of all, there is a chapter on *Cognitive grammar,* written by Ronald Langacker, the founding father of this discipline. Cognitive grammar is the antipode of the Chomskyan approach to language, stressing the central role of general cognitive principles in language and the language user's sensori-motor interactions with his surroundings.

Secondly, there are chapters that offer a general introduction to the broad field of language and cognition. The most general one is a chapter with a title that is the umbrella term for many separate lines of research in the field: *Cognitive science.* In this paper, Seana Coulson and Teenie Matlock describe the separate angles from which language is studied within a cognitive framework and review the major research techniques. Another chapter is a methodological one, in which a frequently used method in research on language and cognition is discussed: the experimental method. This chapter, *Experimentation,* written by the present author, describes a number of essential notions for setting up a sound experimental design and describes the rationale behind statistical testing in general and the most frequently used statistical tests in particular.

Further, there are chapters with a focus on developmental issues. In the chapter *Developmental psychology,* written by Susan Ervin-Tripp, the major research topics, theories on cognitive development and research methods are discussed. Additionally, the author relates questions in developmental research to issues in pragmatics. Another chapter zooms in on one particular aspect of development: the acquisition of language. In their chapter on *Language acquisition,* Steven Gillis and Dorit Ravid give an overview of the different theoretical perspectives on language acquisition, ranging from the nativist to the empiricist perspective. They describe a variety of possible bootstrapping mechanisms that an infant can use for getting started in the process of language acquisition, without having to fall back on innate structural constraints. They also discuss different research methods and emphasize variation between and within children. Finally, they point out that language acquisition does not stop at the age of four and that there is a need for studies on older age groups.

Another set of chapters addresses different linguistic levels that can be addressed in studies involving language and cognition. These levels range from the recognition and production of language forms, to issues of semantic categorization and metalinguistic awareness. In the chapter on *Psycholinguistics,* the present author describes how this discipline was founded and how it can be defined in terms of its major goals, theoretical models, research methodologies, and techniques. He then covers the literature on psycholinguistic research that has been performed with respect to the four language modalities: visual word recognition (reading) and production (spelling), speech perception and speech production. As a review of each of these four research domains could form a chapter of its own, the chapter on psycholinguistics is longer than other chapters in the volume. There are two more chapters dealing with psycholinguistic topics. In the chapter on *The multilingual lexicon,* Ton Dijkstra addresses the question whether speakers of multiple languages have separate mental lexicons for each language, inhibiting the irrelevant one(s), or whether words from all languages are stored together in a single mental lexicon and activated language-independently. He discusses studies that support the single lexicon idea, citing evidence obtained with different experimental techniques. In the chapter on *Comprehension vs. production,* J. Cooper Cutting raises a question that has concerned many psycholinguists: is comprehension the sequence of production processes in reverse, and vice versa? He tackles this question with respect to research on the mental lexicon and on syntactic processing. A chapter by Roger Lindsay, *Perception and language,* moves to a higher level of language. The question is raised to what extent the knowledge of a language affects our perception of the world and the operation of higher-order cognitive processes, which leads to the Sapir-Whorf debate. However, the larger part of the paper addresses a set of possible interactions between language, perception, action, and consciousness. The contribution by Eleanor Rosch, *Categorization,* describes the classical view, which defined categories (concepts) as sets of individually necessary and collectively sufficient conditions and how this view had to make place for a theory in which graded structure and the notion of prototypes became the central notions (her own theory). She describes how this new view was mathematically modeled and how some researchers attempted to salvage the classical view by construing hybrid theories. Still one level higher up the ladder of linguistic abstraction we find humans' ability to reflect on their own language use. This reflexive capacity, one of the defining features of language use, is addressed by Elizabeth Mertz and Jonathan Yovel in their chapter *Metalinguistic awareness.* A chapter by Wallace Chafe on *Consciousness and language* also addresses our capacity to be aware of our own speech production. Chafe argues that there are foci in language that attract our attention, like prosodic units, and discusses the different types of activation costs that are involved when our consciousness is directed on some topic. He argues that intonation units absorb limited capacity, unlike higher-level units, such as discourse topics, which must also attract our attention, even though these take up too much capacity to be active in consciousness all at once.

Finally, the book addresses a number of modern techniques that have turned out to be quite successful for modeling human cognition, particularly language processing. In the chapter on *Connectionism,* Ton Weijters and Antal van den Bosch explain what connectionist modeling actually is. They describe the operation of a perceptron, which is an artificial device that carries out some form of neuron-like computing and can thus be considered the forerunner of connectionist models. They then go on to discuss the algorithm of backpropagation in connectionist models, which are based on the principle of supervised learning. Finally, they discuss the concept of unsupervised learning on the basis of self-organizing feature maps. They also mention ways in which connectionist modeling might be useful for pragmatics. In their chapter on *Artificial Intelligence,* Steven Gillis, Walter Daelemans and Koenraad De Smedt define the symbol system hypothesis, which states that knowledge should be physically represented and that programmes should manipulate these physical symbols. They discuss the various available paradigms for representing knowledge and how linguistic symbols can be manipulated in semantic and pragmatic contexts. In his chapter on the *Cerebral representation of language* Michel Paradis puts the concept of dyshyponoia central, i.e., the language problems that many brain-injured people experience after damage to the right hemisphere: while being able to use and understand the literal meaning of language, they have lost its pragmatic function and have, for instance, trouble with metaphor, metonymy, humor, and other kinds of non-literal language use. The author also addresses these patients' problems with pragmatic inferences, which are not logically required but make the communication work. Throughout the paper Paradis relates different functions to the left and right hemispheres.

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Artificial intelligence

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1. Introduction

Artificial intelligence (AI) is a branch of computer science in which methods and techniques are developed that permit intelligent computer systems to be built.[1] These systems allow the synthesis of different aspects of human and animal cognition: perception, action, communication, problem solving, and learning. We will not be concerned here with the question whether these systems are really intelligent; this is a controversial philosophical issue (see e.g. Copeland 1993; Searle 1984; Pylyshyn 1984; Harnad 1989; Hayes et al. 1992). The meaningful use of a natural language in order to communicate is considered to be a task requiring intelligence, even if the ability of people to speak and understand everyday language were not related to other cognitive abilities.

Mastering language has always been one of the primary goals of AI, not only because language is intimately tied to thought and is the principal means of conveying ideas, but also because of the sheer amount of knowledge it takes to understand language itself. AI therefore sees linguistic and other intelligent tasks as complex information processing problems. Consequently, the use of techniques for the aquisition, representation and application of knowledge is central in AI. The main research questions to be addressed in an AI approach are which knowledge sources are necessary, which problem solving strategies should be used, and how all of this can be represented, stored and processed on a digital computer. Much of the research in AI has led to theories of problem solving and knowledge representation in general. Language processing tasks such as production and interpretation are often seen as particular instances of more general problem classes. This has led to the use of powerful paradigms, e.g. parsing as deduction, parsing as search, language generation as planning, etc. (see Allen 1994, for a recent overview).

The aim of AI with respect to language is to develop computational models of the knowledge and the processes involved in executing linguistic tasks including speaking and writing, understanding, learning a language, and several more specific skills such as translating and correcting. The motivation can be to use these models as a basis for theories about

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human language processing (Dijkstra & De Smedt 1995), but it can also be to study the formal, mathematical properties of languages or the computational properties of language processes. The computational study of natural language is often referred to as *natural language processing* (NLP) or *computational linguistics* (CL), although not every computational linguist would see his/her work as belonging to AI. Computational linguists with a background in linguistics or theoretical computer science (in particular formal languages and automata), tend to concentrate on syntax and model-theoretic semantics. The applied wing of CL aims at solving practical problems, for instance by building and commercializing automatic translation aids or natural language interfaces to databases. This is often called *language technology* or *linguistic engineering*.

In this text, we will introduce only the central assumptions and methods of AI in general, and of CL in particular. There are several good textbooks and reference books that can be used to get a deeper knowledge about the concepts introduced in this chapter. Two recent textbooks on AI are Winston (1993) and Luger & Stubblefield (1993). They also include chapters on CL formalisms. The *Encyclopaedia* of AI (Shapiro 1992) and the *Handbook* of AI (Barr & Feigenbaum 1989) can be used to find brief introductions to all subfields and most concepts in AI and CL, and contain numerous references to the AI literature. Two excellent textbooks especially devoted to CL are Gazdar & Mellish (1989a, b) and Allen (1994).

Computer programming is an essential skill for anyone who wants to develop AI models. Languages like Lisp and Prolog are especially suited to implement the formalisms discussed in this chapter. Winston & Horn (1989) and Norvig (1992) are excellent textbooks to learn how to write AI programs in Lisp. Bratko (1990) and Flach (1994) do the same for Prolog. Gazdar & Mellish (1989a, b) introduce the most important CL formalisms together with their implement-ation, and exists in both a Prolog and a Lisp version. Pereira & Shieber (1987) is a classic introduction for learning how to implement CL formalisms in Prolog.

The remainder of the chapter is organized as follows. After a brief note on the history of natural language processing in the framework of AI, the central aims and methodology of AI will be introduced. We will then turn to the notion of knowledge in AI: its representation and use, and an overview of the principal formalisms of knowledge representation. Next we will discuss how knowledge representation is put to use in the various strata of the linguistic system, and we will devote special attention to pragmatics-related issues.

2. A brief historical note

In the early sixties, a number of computer programs were devised that enabled people to communicate with computers in natural language. For instance, Baseball (Green et al. 1963) enables a user to query the system about the dates, locations, teams and scores of baseball games. Baseball answers questions like *Who beat the Yankees on July 4?* The system is an example of a natural language interface to a database: the user enters natural language text which is transformed by the system into a formal query. On the output side, the retrieved data are presented to the user in the form of a natural language sentence. Other examples include Protosynthex1 (Simmons et al. 1964), a question-answering system that has as its domain the contents of a children's encyclopedia, and Student (Bobrow 1968), a system that is able to find sets of equations in algebra story problems and solve them. Lunar (Woods et al. 1972) answers question about lunar rocks; it is one of the first systems using a sophisticated linguistic formalism, *augmented transition networks* (ATNs) to process natural language (Woods 1970).

One of the most famous examples is Eliza (Weizenbaum 1966), a program that converses with its user in English by accepting any input and responding more or less appropriately. A particularly popular 'impersonation' of the program is the simulation of a Rogerian psycho-therapist conducting an initial interview with a patient. The dialog between Eliza and its patients looks sophisticated at first sight, as can be seen in the following abstract:

Eliza: Earlier you said that you were having trouble with the computer.
Patient: That's right and it hasn't got any better.
Eliza: What does that suggest to you?
Patient: That computers are no use.
Eliza: How would you react if machines took over?
Patient: I think it would be a disaster.
Eliza: Does anyone else think it would be a disaster?
Patient: Yes quite a lot of people.

This dialog is taken from a mini-version of Eliza (McTear 1987). The program does not really understand the input: it scans the input for particular *keywords* and then generates an automatic response. For instance, the phrase *I think* triggers a response asking if also other people have the same opinion. It also uses particular phrases that are meant to show interest by simply reflecting the patient's words or to prompt the patient for further input (as for instance, *What does that suggest to you?*). Of course, the particular communicative setting, where it is generally the patient who talks and the therapist prompts the patient, enables the program to carry on this superficial conversation strategy. However, the fact that even psychotherapists entertained the idea that a refined Eliza might be able to substitute a human psychotherapist (Weizenbaum 1984) suggests that artificial language users can ultimately pass the Turing test (Turing 1964), which would mean that humans are not able to distinguish a human from an artificial language user.

More importantly, Eliza illustrated some general purpose *heuristics* that can be used to model conversational behavior. Heuristics are strategies or guidelines for solving problems. This line of thinking has been pursued in later research on conversational computers and in intelligent interfaces to software programs.

The early attempts at having computers understand and produce natural language are fairly restricted in a number of respects. Only a very limited number of topics can be talked about using a restricted *subset* of the language. Furthermore, some of these systems look for *keywords* in the input that trigger particular responses, so that no serious linguistic analyses have to be performed. And finally, dialog is restricted to questions and answers, and no further transactions are possible. In this respect the early systems represent a *result oriented approach* to language processing, i.e. the main emphasis is on satisfying or impressing the user, rather than on *cognitive simulation*. Later approaches did in fact adopt a more cognitively and linguistically motivated perspective. Shrdlu (Winograd 1972) can be seen as one of the earliest examples of such an approach.

The domain of discourse of Shrdlu is a tiny model world of colored blocks, pyramids and a box, all of which can be manipulated by a simulated robot arm. (See the Blocks World model visually presented in Winograd 1972: 12.) On a screen, the system's manipulations in the Blocks World are projected, and the robot is able to converse in writing with a person. The person can ask the robot to stack blocks, put them at different locations, etc., or ask the robot questions about its understanding of its world. For instance, a person can order the robot to *Put the blue pyramid on the red block* or ask *How many things are on top of the green cube?*

Clearly, the robot needs some nontrivial sense of language understanding to carry out such orders or describe the state of affairs. The system is able to detect the ambiguity in the sentence *Put the green block on top of a red one;* it would ask the person if by *on top of* she means *directly on the surface* or *anywhere above* (in case there was already another object on the red block). It also understands that *a red block* means no matter which one. Moreover, the system contains knowledge about how to intelligently stack blocks, for instance, that it is impossible to put a block on a pyramid, and that in order to put a block directly on another one, the second block has to be cleared first. In addition, the system could learn new words and their meaning, for example *steeple*.

One of the key innovations that Shrdlu embryonically established is the systematic representation and use of two interlocking kinds of knowledge: *linguistic* knowledge, pertaining to the syntax and the semantics of the language, and also *world* knowledge, encapsulated in a pragmatic component. It was made clear that understanding and producing natural language requires substantial amounts of knowledge about the *domain* of discourse, as well as reasoning about the *structure* of the discourse. It also became clear that handling the knowledge needed in a toy world is one thing, but designing a system for the real world is another. Scaling up a system is a formidable problem which involves gathering vast amounts of knowledge and finding out how it relates to the processes of language understanding and generation.

The importance of knowledge, especially background knowledge, and the ability of the language user to bring that knowledge to bear on the process of language comprehension and production, has been widely recognized in a number of approaches that have been traditionally labeled *pragmatic*, such as speech act theory, discourse processing and conversation analysis. The added value of an AI approach in this respect is the requirement that knowledge of whatever kind has to be dealt with explicitly in order to arrive at a working program. AI research provides a whole range of techniques to support the design of a knowledge base, its formal representation, and the implementation of the mechanisms to manipulate the knowledge. The whole can be tested by means of computer simulations, and shortcomings can be traced.

In conclusion, the introduction of specific language processing techniques in AI systems such as SHRDLU have resulted in a new type of human-computer interaction. Later systems generally incorporate knowledge about syntax and semantics for parsing and generation of sentences, discourse representation, text planning and dialog management facilities. Moreover, a detailed domain model and explicit models of the user are added. User models infer the user's knowledge, goals and plans, which are needed to tailor the system's interactions with the user. Knowledge about the domain provides the means for inferring connections between objects and events that are often left implicit in natural discourse. It also creates the basis for inferring new knowledge from known facts.

3. The physical symbol system hypothesis

Allen Newell received the 1975 Turing Award for showing that computers can be seen as general symbol manipulators and not just as number crunchers. With Herbert Simon, he formulated the *physical symbol system hypothesis* (PSSH; Newell 1980), a central hypothesis in both AI and cognitive science. According to the PSSH, concepts are mentally represented by physical symbols. The term *physical* means that the symbols should be implemented in some sense in physical reality, for example as electrical states in a computer memory. Relations between concepts are represented by structures of physical symbols. Mental processes are represented by physical processes that can be written as programs manipulating physical symbol structures (see Figure 1). Programs are also represented as symbol structures, so that they can be manipulated by other programs. Because of this recursion, learning can be explained within this framework: the mind can change itself in useful ways by manipulating its own mental structures and programs by means of a learning program. According to the PSSH, the manipulation of symbol structures is necessary and sufficient for intelligent behavior.

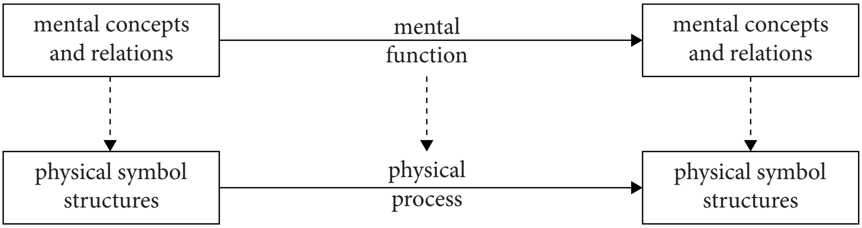

Figure 1. Mental functions are represented by processes operating on physical symbol structures

A consequence of the PSSH is that intelligence is independent of the physical level, and can be described at an implementation-independent level. In other words, the hypothesis works regardless of whether physical symbols are located in the human brain as networks of neurons, or in a computer memory as electrical states.

The PSSH leads to a research methodology in AI in which a particular task or type of intelligent behavior is simulated by designing a computer program manipulating symbolic representations. A program translating English into French by manipulating symbols representing English and French words and using symbolic representations of the translator's knowledge, is an instance of a program simulating intelligent linguistic behavior in a symbolic way.

The approach followed in designing an AI system is usually a variant of *problem reduction:* a task is decomposed into a number of simpler subtasks which can be further decomposed until subtasks are distinguished which can directly be implemented. Another design principle is *modularity:* the program achieving a task is divided into different modules, often corresponding to major subtasks, which are more or less autonomous, specialized information processors.

Within each module, the AI approach aims to put together the necessary knowledge and methods needed for that module to accomplish its task. This information needs to be captured in a *formalism* for the representation and manipulation of knowledge. At this point, it is useful to reflect on the role of formalisms in AI in general and in linguistic models in particular. A formalism is a description language that provides a bridge between theory and implementation. A formalism consists of two parts:

1. The *data organization* part contains a description of the domain entities, properties and relations involved. It provides the means with which the necessary knowledge is described. In a language processing model, this could be lexical information and grammar rules, among other things.
2. The *inference* part determines methods for how the data can be used to solve a problem. Specific methods include logical resolution, a production system interpeter, etc., which will be described below.

In recent research in CL, there has been a shift from *procedural* to *declarative* formalisms. A procedural formalism tightly integrates data and inference. This allows the model to use inferences which are local to specific instances of knowledge. But the directness and specificity of this approach is countered by severe problems in extending and updating such a system. For that reason, declarative models, which make a clean separation between knowledge representation and inference aspects of a problem, dominate the field.

4. Paradigms for the representation of knowledge

In this section, we will discuss some aspects of knowledge representation that have been used for the representation of knowledge in general, and linguistic knowledge in particular.

4.1 State-space search

A *state-space* is a tree structure consisting of *nodes* and *arcs*, as illustrated in Figure 2. Nodes describe states representing situations in the domain, e.g. the description of a chessboard with a number of pieces. Some nodes may describe goal states, e.g. a chessboard on which the white king is checkmate. Arcs in the tree describe the transition from one state to another by the application of an operator, e.g. an operator for moving a pawn. Arcs have an origin (the state to which the operator is applied), and a destination (the state which results from applying the operator). In CL, search is used e.g. in parsing sentences. Suppose we have a simple grammar with rewrite rules like the following:

S	→	NP VP
NP	→	N
NP	→	Pro
VP	→	V NP
VP	→	Aux V
Pro	→	they
N	→	can | fish
Aux	→	can
V	→	fish

In the case of parsing a sentence with this grammar, states are partial derivations consistent with the grammar and the input sentence, and operators are the state changes that different applicable grammar rules may make. Figure 2 illustrates this in a simple way by showing a tree representing the state space of analyses, some of which lead to a successful analyses. In this case, the parsing proceeds *top down*, i.e. by expanding the *left-hand* side of rules to the *right-hand* side, working from the root node *S* down to the words.

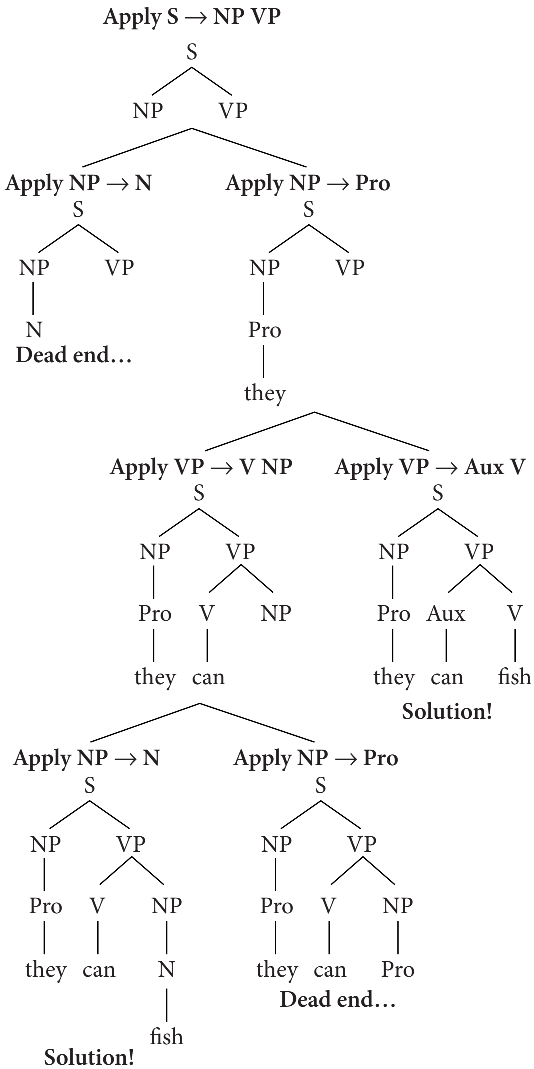

Figure 2. State-space of a syntactic parsing

Search methods are algorithms allowing a state space to be searched for solutions to a problem. Search methods can be *blind*, which means that all possible states are tried in the end by the search method, either in a *depth first* or a *breadth first* way, or they can be *heuristically informed*, in which case they make use of knowledge about the domain to traverse the state space (Pearl 1984).

4.2 Logic-based formalisms

In one view, *logic* is the standard knowledge representation formalism in AI, because it embodies basic principles of reasoning, such as *modus ponens* and *modus tollens*. It has been called by Sowa (1991) 'the assembly language of knowledge representation'; it is indeed a low level formalism, in its complexity and verbosity far removed from the conciseness of natural language. Nevertheless, the formal properties of logical formalisms make them ideally suited as a language to which other formalisms can be translated in order to evaluate and compare them.

Data organization in *predicate logic* consists of a set of unambiguous *constants* representing entities in the domain, a set of unambiguous *predicates* representing relations between entities in the domain, a set of *functions* between sets, and furthermore *variables*, standing for any entity, *quantifiers* such as *all* and *at least one*, and *logical connectives* such as *and* and *or*. Inference in predicate logic is achieved by applying *deductive principles* such as *resolution*. In pure predicate logic, inference is not easy, i.e. it is not computationally tractable, but limited versions have been defined that make inference tractable, e.g. by the combination of *Horn clauses* and *negation by failure* in PROLOG (Clocksin & Mellish 1984). Below is a very small PROLOG program expressing the facts that Socrates and Plato are human, and the rule that if *x* is human, then *x* is mortal:

```
human(socrates).
human(plato).
mortal(X) :- human(X).
```

The choice of the right constants, predicates, functions and axioms for solving a particular task is the main problem in designing a logic-based solution to language processing problems. Predicate logic has some severe limitations as a tool for representing linguistic knowledge which is incomplete, inconsistent, dynamically changing, or relating to time, action and beliefs. For all these problems, special-purpose logics are being designed (Ramsay 1988). In this research, attention tends to shift from the domain to be represented (language knowledge and processes) to the formal properties of the representation formalism.

In the area of semantics and pragmatics, several logic-based approaches of reasoning and argumentation have been proposed. As one example, we mention the work of Lascarides and Oberlander (1992) on the nontemporal order of utterances with causal relationships, as in *John fell of the cliff. The bitch pushed him.* They explain this by linking the events by means of logical *abduction*.

4.3 Semantic network formalisms and frames

Semantic networks were introduced in AI in the sixties as a model for human semantic memory (Quillian 1968). A semantic network consists of named *nodes* representing concepts, and labeled *links* representing relations between concepts. Nodes can be used to represent both types and tokens. For example, the semantic network in Figure 3 expresses the knowledge that birds have skin, wings, and can fly. A special link, the IS-A link allows inferences to be made via *inheritance*. In the network of Figure 3, *sparrow* is connected via an IS-A link to *bird*, allowing the system to infer that sparrows have wings and skin and can fly without the necessity to explicitly represent this (see Sowa 1991 for an overview of recent research on semantic networks).

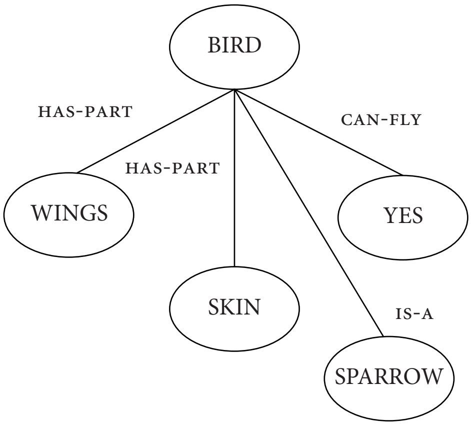

Figure 3. A semantic network

In order to incorporate more structure into associative networks, *frames* were proposed as a representation formalism by Minsky (1975). Each frame can be viewed as one encapsulated chunk of a semantic network. Links in semantic networks correspond to *roles* in frames. When used to represent natural language semantics, roles may be used to represent *thematic roles (case relations),* among other things. For example, a frame for a *kiss* action may have an *agent* role and a *recipient* role. These roles are filled by fillers which are themselves frames, for example, the *agent* may be *Susan* and the *recipient* may be *Jim*. Frame systems may allow complex descriptions of roles by adding *defaults* for the filler of a role, *constraints* on the filler of a role, and attached *procedures* to compute the filler of a role. Consider the following frames:

KISS-ACTION
    AGENT: Type = a PERSON
    RECIPIENT: Type = a PERSON or OBJECT

KISS-1
    ISA KISS-ACTION
    AGENT: SUSAN
    RECIPIENT: JIM

PERSON
    AGE: Procedure = subtract BIRTH YEAR from CURRENT YEAR
    BIRTH YEAR: Type = a NUMBER
    NUMBER-OF-LEGS: Default = 2

JIM
    ISA PERSON
    BIRTH YEAR: 1970

SUSAN
    ISA PERSON

In a frame-based system, an input activates one or more frames, which consequently allows inferences to be made on the basis of the input. Attached procedures (such as the one to compute the age of persons) enable local inferences. Other inferences are based on *inheritance* along IS-A-links. Whether such inferences are interpreted as *predictions, preferences,* or *defaults* depends on the program using frames as a source of knowledge. In general, information that is inherited from other frames is default information, which means it is defeasible by more specific information. For an overview of the use of inheritance in CL, we refer to Daelemans, De Smedt & Gazdar (1992).

4.4 Rule-based formalisms

In a rule-based formalism, knowledge is cast in the form of *if-then* rules: *IF* X *THEN* Y. For example, a rule for producing questions may be the following: *IF the intention is to query the truth of P, THEN produce a yes/no question about P.* If-then rules, also called *condition-action* pairs or *production* rules, were developed during the seventies as a model for human problem solving (Newell & Simon 1972). The rules can only produce actual behavior with the help of an *interpreter* which performs a *cyclical* process where each cycle consists of three phases:

1. *Identification*. This phase determines for which rules the condition sides are currently satisfied in working memory.
2. *Selection*. It will often happen that more than one rule's condition side will be satisfied. Since it is in general not desirable for all applicable rules to fire, one or more rules are selected using a criterion, e.g. the first rule found, or the most specific rule.
3. *Execution*. The actions of the chosen rule are executed. Although such actions can take many forms, the most typical ones involve the addition to or removal from working memory of certain facts. Some of the facts added may represent a solution to the given problem.

Production rule systems allow both *forward chaining* and *backward chaining*. In forward chaining, inference is *data-driven*, i.e. states in working memory activate rules when their left sides match the current state. Execution of these rules may in turn activate other rules or achieve goals. In backward chaining, inference is *goal-driven*, i.e. goals are asserted and conditions of rules achieving the goals are introduced as new goals when they are not present in working memory. In the latter case, the right-hand side of the rules is used to identify applicable rules.

The rule-base acts as a kind of *long-term memory*, whereas the working memory, which describes the conditions that are satisfied at some point during computation, acts as a *short-term memory*. Rule-based architectures have been further developed toward more sophisticated cognitive models e.g. Act* (Anderson 1983) and Soar (Newell, Rosenbloom & Laird 1989). The Act* system has a semantic network as part of its long-term memory. Soar contains special mechanisms for remembering the results of previous computations in long-term memory.

5. Linguistic symbol manipulation in semantics and pragmatics

Following the methodological principles of problem reduction and modularity, the task of generating or interpreting natural language is usually decomposed into subtasks so as to make the modeling of the task more manageable. Subtasks and modules in CL systems are usually more or less tied to the unit of processing, i.e. the phoneme, word, sentence, and discourse. On the side of language understanding, they often consist of *speech recognition, morphological analysis, syntactic parsing, semantic analysis,* and *discourse analysis*. On the side of language generation, they often include *discourse planning, sentence generation, morphological generation* and *speech production*. There are several possible architectures depending on how these modules interact.

One possible scheme for the interaction between those modules is a *stratificational* (or *sequential*) architecture. In this architecture, the different modules are accessed in sequence, and any output of one component is directly input to the next component. Clearly, other kinds of architecture are possible with more interaction between the different modules. In an *interactive* architecture, there is feedback between a module and the previous one. In *blackboard* architectures, modules communicate via a common channel called the *blackboard*; in *object-oriented* designs, objects representing parts of modules communicate via *message passing*. In *localist connectionist* systems there are weighted links that allow one symbol to directly activate other ones. *Distributed connectionist* systems, finally, allow several concepts to be implemented using the same set of units, depending on their activation pattern, making even the representation of symbols interactive (Murre & Goebel 1995).

Especially in the integration of syntax and semantics, several nonsequential architectures have been proposed. Syntactic ambiguities, which can run into the hundreds or thousands for normal sentences, can often be resolved as a natural side-effect of solving semantic ambiguities. Therefore, a stratificational 'syntax first' strategy, in which all possible syntactic parses are computed first and are then input to the semantic component, is impractical, and many AI researchers have tried to integrate these two modules (e.g. Waltz & Pollack 1985).

In the next two sections, we will give an overview of selected CL research in the framework of AI and we will focus on semantics and pragmatics. The modeling of phonology, morphology and syntax have traditionally been the realm of the more linguistically oriented researchers. We will not go into these issues here.

5.1 Semantics

Much of the early symbolic AI research on natural language understanding uses *associative network* formalisms to represent its theoretical insights. Schank (1972, 1975, 1980) and his students developed *conceptual dependency theory* as an associative network formalism for the description of the meaning of sentences and texts. These networks are somewhat related to semantic networks (see above), but they have severe restrictions on possible nodes and links. A limited number of node and link types are designated as conceptual primitives. Node types for actions include, for example, *physical transfer, mental transfer*, etc. These are seen as the basic elements in the language of thought, and expressions composed of these primitives are supposed to be necessary and sufficient as an *interlingua* to represent meaning in an unambiguous way. Any implicit information in the text is to be made explicit in the conceptual dependency representation. For example, the information in the sentence *John gave the book to Mary* is analysed in terms of a transfer (ATRANS) of the book (the object) from John (the donor) to Mary (the recipient), involving a change of ownership. *John loaned the book to Mary* has obviously an analogous underlying information structure, except that in the latter case possession but not ownership is involved. The conceptual dependency structures of both sentences are illustrated in the following graphs:

John gave the book to Mary.

John loaned the book to Mary.

The general goal of conceptual dependency theory (viz. to capture meaning in language-independent knowledge structures) gave rise to the development of a large number of related data structures and inference mechanisms. Causal chains are data structures representing chains of states enabling or motivating actions which in turn result in or initiate other states; scripts are prepackaged sequences of causal chains. Other data structures include plans and goals, memory organization packages (MOPS), and plot units (Schank & Abelson 1977; Schank 1982). These knowledge structures made possible directed and efficient inference mechanisms, based on following up causal connections and associations between representations at the same and at different levels of abstraction.

The work by Schank and his students also made clear that two sources of knowledge are indispensable for developing useful symbolic natural language understanding systems: (1) knowledge about the intentions, plans and goals of different agents in narratives or dialog, and (2) knowledge about preceding discourse. This work belongs to what is commonly understood as pragmatics. We will now go into some more detail about particular aspects of this research.

5.2 Knowledge and intentions

As to the speaker's intentions, *speech act theory* has been an important source of inspiration. Cohen & Perrault (1979) and Allen & Perrault (1980) view linguistic behavior as *goal-driven planning*: the speaker plans an utterance in order to achieve a communicative goal, while the listener's aim is to infer that goal from the linguistic form. Speech act theory articulates the specific goals and plans a speaker may have in using language. A specific example, adapted from Wilensky (1983), involves the goal and associated plan for *asking*, including the *preconditions* that need to be satisified for the plan to be successful:

Goal:	X wants to find out P from Y
Act:	Ask question to Y
Preconditions:	1. X is near to Y
	2. Y knows P
	3. Y wants to tell P to X
Result:	Y tells P to X

The goal-directed and plan-based view of linguistic behavior has been widely adopted and is still a topic of current research in the AI community (e.g. Kobsa 1989; Carberry 1989; Cohen et al. 1990).

The underlying conceptual representation in a cognitive psychology approach is the source of further reasoning. In order to arrive at an answer to a question, it is often insufficient to convert the question directly into a database query, but frequently inferences have to be drawn. This is acknowledged by Lehnert (1978) in her discussion of QUALM, the reasoning component of a question-answering system using Schank's conceptual dependency. Answering a question involves various manipulations of the conceptual structure underlying the question, such as inferring what entity or entities is/are actually referred to by a *wh*-word.

Consider for example the question *Who wasn't at the party?* Probably a considerable part of the world's population was not present, but a reasonable inference is that the question refers only to *invitees* who did not show up. Even in order to answer a fairly simple question such as *Did John eat a steak?* when he is sitting in a vegetarian restaurant or when he simply left after seeing a hopelessly burnt piece of meat, a lot of inferencing is needed. Besides a conceptualization of the events mentioned, knowledge is also needed about inferred events that probably occurred but were not mentioned, failed expectations, etc. These can be made on the basis of knowledge about stereotypical situations as well as general knowledge about how people achieve goals and what sorts of goals they try to achieve (Wilensky 1983).

5.3 Utterances in context

As a matter of course, many of the issues that are raised in discourse and conversation analysis also turn up in the computer processing of natural language. For a correct interpretation of an utterance, the hearer needs to take into account the context of the communication, including the situational context, the participants' knowledge of the domain and their intentions, and the links between the current utterance and those that precede it. Questions in point relate to the identification of the referents of *definite noun phrases*, to *anaphora* resolution, etc. Much of the AI work on discourse processing has been restricted to fairly simple discourse types with a strong tie to a particular task. For instance, Grosz (1977) studies interactions in which an expert instructs an apprentice on how to assemble an air compressor. Grosz shows that it is possible to formulate *focusing heuristics* because the task restricts what is talked about: the structure of the task is mirrored in the dialog structure. Similarly, Carberry (1989) establishes focusing heuristics that rely on the expectations of possible shifts of focus constrained by the underlying task-related plan in an information-seeking dialog.

The cooperative nature of the discourse types studied also aids in establishing *coherence* relations. For instance, McKeown (1985a, b) expanded the focus rules designed by Sidner (1983, 1985) in her computational work on discourse generation. Her approach is based on the observation that people follow certain standard patterns or *schemas* of discourse generation (see below) for attaining discourse goals. These patterns are helpful for the listener or reader in establishing the thread of discourse and are thus an aid in understanding (Carberry 1989).

A number of computational models have been proposed for the comprehension of discourse, but they tend to ignore its complexities (Garnham 1995). Several AI systems tend to treat discourse as a product, for which stereotypical knowledge structures can be implemented. Reichman (1985), for instance, proposes a kind of grammar for discourse, consisting of formal discourse rules and an ATN formalism for analyzing discourse. This sharply contrasts with the approach taken in conversation analysis research, in which dialog is seen as an interactional achievement. The more or less stereotyped AI approach on the one hand and the dynamic approach advocated by conversation analysts on the other hand have been conceived as irreconcilable opponents, though a fruitful interaction that may enrich the flexibility of human-computer interaction is advocated by Luff et al. (1990).

5.4 Modeling the user

User models are specific components designed for a better understanding of the user of a computer system. They have been included in AI systems that perform various tasks. The Unix Consultant (UC), a natural language program assisting beginning Unix users, contains a component Knome which maintains a model of the user (Chin 1989; Wilensky et al. 1988). Some other systems which maintain user models are Grundy, which recommends novels to users in a library setting (Rich 1979), Ham-ans, which assists a user in renting a room in a hotel (Morik 1989), and Xtra, which acts as a tax advisor assisting the user in filling out his/her income tax form (Kobsa et al. 1986). In all these systems, a model of the user is part of a dialog component. However, it can readily be seen that user modeling is an important aspect of other AI applications such as intelligent computer aided instruction, in which a teacher must monitor the knowledge of the student, and game playing, in which a system should take into account the perspective of its adversary in order to figure out what his/her plans and goals are.

5.4.1 *User modeling and dialog systems*

In the context of dialog systems, a user model can be defined as a knowledge source which contains explicit assumptions on all aspects of the user that may be relevant to the dialog behavior of the system. Allen (1994) argues that regardless of whether the dialog is cooperative or not, a user model is the basis for intelligent dialog behavior. Among other things, it is required for identifying the objects talked about, identifying and analyzing non-literal meanings or indirect speech acts, determining the effects of the planned contribution on the listener, etc. As such, a user model is a crucial component of a dialog system: it provides important information for understanding the dialog partner as well as for producing an appropriate response.

The assumptions gathered in a user model must be separable by the system from the rest of the system's knowledge, and must be supplied to other components of the system which need them (Wahlster & Kobsa 1989). The intended separation between implicit and explicit models of the user stands in contrast to current practice in the field of human computer interaction (HCI, software ergonomics or cognitive engineering), where the designer of a software product has a typical user in mind, but the definition of that user is hidden in the system without being explicitly articulated; it can only be inferred from, e.g. the design of the user interface (Norman 1986; Helander 1988). In a dialog system, the concepts *user model* and *discourse model* are closely related. The exact relationship is still a matter of debate (see for instance the discussion of this topic in *Computational Linguistics* 14/3).

5.4.2 *Dimensions of user models*

There are various dimensions along which user models vary (Kass & Finin 1988). A first distinction is that between a canonical user model which accounts for all users and an individual user model which is specific for a single individual user. Canonical user models do not take into account the characteristics of individual users; once the latter come into play, a model must be explicitly maintained by the system and mechanisms must be provided for instantiating, updating and exploiting the model.

A second dimension concerns the long term versus short term user model. In the former, relatively stable or static characteristics of the user are represented, while in the latter specific interactional information (such as topics discussed, goals pursued, etc.) is stored. In this perspective the concept of a user model shows close correspondence with that of a dialog model: a short term user model actually overlaps with a dialog model in that it records the specifics of the interaction (Rich 1989; Kobsa 1989).

5.4.3 *Construction of a user model*

There are essentially two paths followed in constructing a model of the user. First of all, the actual input of the user is a prime source from which his/her knowledge of the domain, as well as his/her plans and goals can be inferred. Secondly, this method can be combined with an approach that assumes *a priori* knowledge present in the system about types of users which is used as a basis for drawing the profile of an individual user.

The notion of a stereotype is useful for initiating a user model. Rich (1989) observes that facts about people tend to be interdependent in that particular traits of people appear to be clustered, forming *stereotypes* which each stand for a class of users. Rosch & Mervis (1975) use the term *prototype* as the denotation of such cognitive reference points. Stereotypes or prototypes enable a system to infer a whole set of user characteristics on the basis of a relatively small number of observations. For instance, in the user modeling component Knome of the Unix Consultant (Chin 1989), users are characterized by four stereotypes: *novice, beginner, intermediate,* and *expert,* each of which represents an increasing mastery of the Unix operating system. An individual user is an instantiation of the stereotype and is assigned its default characteristics. In order to set up a model of an individual user, it is necessary to collect information from the user. This can be done in various ways:

- Users can be asked to classify themselves at the beginning of an interaction, as in Crundy (Rich 1989), or the Real Estate Agent (Morik & Rollinger 1985).
- The user modeling component can be conceived in such a way that it 'looks over the shoulder' of the user and compares the user's performance with that of its own built-in expert system. It is then possible to compare both and to deduce overlap and discrepancies between the user's knowledge and the system's in order to draw a map of the user's knowledge.
- User input can be analyzed to infer what knowledge about the domain it reveals, as in Knome. A stereotype as introduced so far can now be seen as a set of assertions, irrespective of the way in which assertions are represented in the system. Rich (1989) points out that stereotypes may be incorporated in a generalization hierarchy so that the mechanisms of (default) inheritance hold between the members in the hierarchy.

An important feature of the use of stereotypes is that the system can infer what users are likely to know or not, which user characteristics are likely to hold or not, based on only partial information about the user. In other words, the inference that a user belongs to a particular class defined by a stereotype enables the system to make a set of default inferences, which are plausible but defeasible. In order for these to work properly, uncertainty measures are associated with inferences, either as numerical values or as symbolic ratings of uncertainty (Rich 1983, 1989; Chin 1989). Moreover, in order to recover from contradicted inferences, not only the assertions about users are recorded, but also the justification of these assertions are noted, so that some form of *truth maintenance* (Doyle 1979, 1983) can be assured. Truth maintenance guards the consistency of the model and is an important feature of user modeling attempts for specific domains as well as user modeling shells such as Gums (Finin & Drager 1986; Finin 1989) and Trump (Bonarini 1987).

5.4.4 *Instantiating the user model: Collecting evidence in dialog*

The context of user modeling in dialog behavior should be clarified before we can show how user models are instantiated, updated and exploited. Most of the systems that have been developed so far deal with user-system interactions in which the system is to assist the user in some way. For instance, the system provides information that the user asks for: *How can I remove a file?* is a possible query to the Unix Consultant (Chin 1989). A similar interaction arises in a natural language interface to a database: *Which students got a grade of F in CS105 in Spring 1980?* is a possible question envisaged by Co-op (Kaplan 1982), to which the system may respond: *CS105 was not given in Spring 1980.* Another communicative goal is explanation. The following is a sample question addressed to Quilici's (1989) Unix Advisor: *I tried to remove a file with the rm command. But the file was not removed and the error message was 'permission denied'. I checked and I own the file. What's wrong?* To this, the system replies: *To remove a file, you need to be able to write into the directory containing it. You do not need to own the file.*

In the context of interchanges such as these, a system is supposed to draw a user profile. This includes a model of what the user knows, e.g. in the above example, the user knows which command to use to remove a file. It also includes the goals of the user, e.g. the user wants to remove a file; and how s/he plans to achieve that goal, e.g. to use the *rm* command to delete a file. At the same time, the system has to infer, among other things, what knowledge is lacking and hence has to be provided to the user, and also what the user's misconceptions are that need to be corrected by means of an explanation; in the above example, the user misconceives the relation between deleting a file and owning it.

In the present case, the system faces the non-trivial task of determining why the user holds a particular belief or assumption, by trying to explain why the system itself does not hold that assumption (Quilici 1989). Hence, this example exemplifies a system that does not only construct a stereotype of the user, but also infers the causes of a user's beliefs, for which the system has to go beyond a static stereotype in order to determine discrepancies between its own beliefs and assumptions and those apparently held by the user. Similar systems have been devised to detect user's object-related misconceptions. Romper (McCoy 1989), for example, tries to explain to the user why a belief that a whale is a fish is actually wrong. Attention has also been paid to planning related misconceptions (Pollack 1986; Wilensky 1983; Wilensky et al. 1984; Chin 1989). The latter work stresses once again the importance of planning and plan recognition in natural language dialog systems (Carberry 1983, 1988, 1989; Grosz 1977; Robinson 1981; Allen, 1983a, 1983b; Allen & Perrault 1980; Sidner 1983, 1985; Litman 1986; Allen & Litman 1986).

5.5 Generating discourse

Generating an extended piece of discourse involves some careful amount of planning. This complex task has conveniently been divided into two subtasks: deciding *what* to say and deciding *how* to say. The former is sometimes called *text planning* or *strategic generation* (Thompson 1977), and involves choices regarding the selection and organization of information. The latter subtask is sometimes called *linguistic realization* or *tactical generation* and involves lexical and syntactic choices for the computation of the linguistic form of the utterance. We will in this section be concerned only with the first subtask, text planning (or discourse planning). Overviews of AI research in natural language generation can be found in Kempen (1989) and McDonald (1992). For proceedings of workshops on computer models for natural language generation, we refer to volumes edited by Kempen (1987), Zock & Sabah (1988), Dale, Mellish & Zock (1990), Paris, Swartout & Mann (1991), Dale, Hovy, Rösner & Stock (1992), and Horacek & Zock (1993). Computational models of discourse planning are reviewed from a psycholinguistic perspective by Andriessen, De Smedt & Zock (1995).

Generating discourse is a multiple constrained process in which various knowledge sources should be taken into account: knowledge of the domain of discourse, the situational context and past discourse, as well as knowledge about the interlocutor or reader. As indicated in the previous section, user models are an important part of discourse understanding, but the user's plans and goals also play an important role in discourse generation. Detecting and using the user's goal to provide an appropriate response has been the object of extensive research (e.g. Appelt 1985; Carberry 1983; McKeown 1985a, 1985b). Even though the use of a specific user model in the generation process has recently been questioned (Sparck Jones 1991), tailoring discourse to the user's level of expertise and taking the user's misunderstandings and other input into account are obviously fundamental communicative abilities (Kaplan 1982; McCoy 1989; Quilici 1989; Reiter 1990; Cawsey 1990a, 1990b; McKeown et al. 1990; Paris 1988; Chin 1989; Moore & Swartout 1991; Moore 1989).

In discourse generation, two approaches can be distinguished. The first approach can be characterized as conceptualizing generation as a kind of *planning* in the AI sense of the word, driven by the communicative goals of the speaker (Appelt 1982, 1985; Cohen & Perrault 1979). This means that at the strategic level, text is planned by reasoning about both the system's and the user's knowledge and beliefs, and that speech acts are meant to have a particular impact on the user's beliefs and knowledge structures. It has been argued that this approach does not incorporate an explicit notion of textual *coherence* and hence will face serious problems when transcending the sentence level (Dale et al. 1990; Moore & Swartout 1991).

The second approach emphasizes *text structuring* above the level of the sentence. To this end, McKeown (1985b) and Paris & McKeown (1987) propose *schemas,* i.e. representations of stereotypical discourse strategies. For instance, McKeown proposes four schemas for describing objects: *identification*, *constituency*, *attributive* and *contrastive* schemas. Schemas mandate the content and the order of the clauses in paragraphs. However, they do not allow the dynamic reassembly of the basic parts into new paragraphs. In order to fix this drawback, McKeown et al. (1990) envisage to generalize schemas into an hierarchy of increasingly more general schemas.

An alternative approach offering a more detailed and dynamic text structuring is *rhetorical structure theory* (RST; Mann & Thompson 1987, 1988). RST identifies basic rhetorical relations as the building blocks from which coherent paragraphs (and thus, ultimately also the schemas mentioned above) are composed. Using RST relations, text generation systems can dynamically put together paragraphs. Some examples of rhetorical relations between elements in texts are SEQUENCE, which is signaled by words like *then*, *next*, etc.; PURPOSE, signaled by *in order to*; and ALTERNATIVE, signaled by *or*. Rhetorical relations are used at several levels of the text structure, down to the level of single clauses. Coherent discourse is attained if all parts of a text can be hierarchically structured by rhetorical relations. Thus, the relations in a stretch of discourse can be represented as a tree structure. The branches of the tree represent adjacent clauses and blocks of clauses between which a particular rhetorical relation holds.

Currently much generation research is devoted to implementations of RST, i.e. the design of planning algorithms that dynamically assemble the elements of a text using RST relations (Hovy 1988a, 1988b, 1990, 1991; Cawsey 1990b; Moore & Swartout 1991; Paris 1988, 1991; Scott & de Souza 1990). Other research deals with *focus* in discourse. Focusing refers to the way in which the writer guides the reader's attention throughout a text. This, in turn, has consequences for the correct interpretation of referring expressions, for example pronouns and definite noun phrases. McCoy & Cheng (1991) investigate how a discourse focus tree can be built parallel to the discourse structure tree to track the focus of attention through the text.

An interesting new perspective is created by the introduction of technologies for *multimodal* human-computer interaction, i.e. using both the modalities of conversation and of graphic interaction. McKeown et al. (1990) describes a system in which text and graphics are used for explanations. Claassen (1992) proposes EDWARD, a multimodal dialog system where graphic interaction in a model world is combined with natural language commands and questions. An added feature of EDWARD is the *continuous linguistic feedback generator* (CLFG) which gives natural language feedback on the user's actions.

6. Epilogue

Symbolic approaches that are based on rules, logic, frames, grammars, or on a combination of these representation techniques, are able to successfully perform complex natural language processing tasks. Thanks to the definition of formal operations as operating on the form of structures, irrespective of their content, symbolic systems achieve a high level of abstraction. Symbolic programming allows for flexibility and creativity. First, new symbols and structures can be created dynamically during program execution. Second, structures can be recursively defined and can thus represent a potentially infinite number of actual structures. And third, programs are also symbolic structures and can thus be created or manipulated by other programs.

However, precisely because of the high level of abstraction, symbolic systems are extremely complex in their handling of special conditions. Each exception requires additional rules and more processing. This is particularly problematic as the system is scaled up, even though the problem of scaling up can be somewhat alleviated by the use of powerful mechanisms such as default inheritance. The data and methods must generally be hand-coded by the system designer, because their complexity makes them hard to acquire automatically. This complexity makes symbolic systems vulnerable in the case of ill-formed or incomplete input and in the case of unforeseen interactions between rules. When a symbolic system goes wrong, it usually does not degrade gracefully, but breaks down completely. Machine learning of natural language from data like corpora or machine-readable dictionaries is therefore becoming an increasingly important topic in CL, as it may alleviate these knowledge acquisition and robustness problems.

While the PSSH goes a long way toward providing a framework for the study of *knowledge-based* intelligence, i.e. intelligence based on the construction and manipulation of models, this is less the case for *behavior-based* intelligence, i.e. intelligent behavior based on direct associations between sensory input and motor output without intermediate models. It is an open research question whether language processing is an instance of behavior-based or knowledge-based intelligence, or both. It also remains to be seen in how far language is a task much like other cognitive tasks, e.g. playing chess, solving algebra problems, or recognizing visual objects, or whether language is special in some ways, i.e. autonomous from other cognitive subsystems and requiring special cognitive mechanisms.

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Categorization

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Categorization, the process by which distinguishable objects or events are treated equivalently, is an inherently pragmatic function, an act of the body, speech, or mind. It is one of the most basic functions of living creatures. Humans live in a categorized world; from household items to emotions to gender to democracy, objects and events, although unique, are acted towards as members of classes. Three basic questions have dominated categorization research: why do we have the particular categories that we do and not others; how are categories acquired, stored, and used; and what is the relation between categories in the mind and the objects, cultural forms, and contingencies in the world?

The history of categorization research reflects successive waves of debate between an abstract, logical, semantics based approach and more pragmatically oriented theories. Research on these issues has undergone roughly four phases: (1) The classical view (the 1920s–1960s). Categories were defined logically and were simply assumed to have defining features. (2) Challenges and alternatives to the classical view (the 1970s). Categories were argued to have a graded rather than defining structure and to originate as non-arbitrary reflections of world/perceiver contingencies. (3) Mathematical models and critiques of graded structure (the 1970s–mid 1980s). (4) Categories as theories (mid-late 1980s–present). It is possible that a fifth phase is presently emerging in which categories and concepts are seen as event based, rather than representation based.

Each of these periods contains an implicit or explicit philosophical position, characteristic types of experimental research, and implications both for the development of categories in children and for the relation of language to categories.

1. The classical view of categorization

Categorization is the area in psychology which deals with the ancient philosophical problem of universals, that is, with the fact that unique particular objects or events can be treated equivalently as members of a class. Most philosophers since Plato have agreed that experience of particulars as it comes moment by moment through the senses is unreliable; therefore, only stable, abstract, logical, universal categories could function as objects of knowledge and objects of reference for the meaning of words. To fulfill these functions, categories had to be exact, not vague (i.e. have clearly defined boundaries), and their members had to have attributes in common which were the necessary and sufficient conditions for membership in the category. It follows that all members of the category were equally good with regard to membership; either they had the necessary common features or they didn't. Categories were thus seen as logical sets.

The philosopher's view of categories entered psychology explicitly in the form of concept learning research in the 1950s. Led by the work of Jerome Bruner and his associates (Bruner, Goodnow & Austin 1956), subjects were asked to learn categories which were logical sets defined by explicit attributes such as *red* and *square*, combined by logical rules, such as *and*. Theoretical interest was focused on how subjects learned which attributes were relevant and which rules combined them. In developmental psychology, the theories of Piaget and Vygotsky were combined with the concept learning paradigm to study how children's ill-structured, often thematic, concepts developed into the logical adult mode. For linguists, the relationship between language and concepts appeared unproblematic; words simply referred to the defining features of the concepts, and it was the job of semanticists to work out a suitable formal model that would show how this relationship could account for features such as synonymy and contradiction. Artificial stimuli were typically used in research at all levels, structured into micro-worlds in which the prevailing beliefs about the nature of categories were already built in (for examples, see Bourne, Dominowski & Loftus 1979). Little surprise that that view remained unchallenged.

2. Challenges and alternatives to the classical view

2.1 Graded structure and prototypes

Psychology first began its study of learning through conditioning experiments such as those of Pavlov. The natural analog of the philosophical problem of universals in conditioning research is stimulus generalization — an organism is conditioned to a single stimulus yet generalizes his response to other "similar" stimuli. But think how unlike the classical view of categories this is. Pavlov's dogs produced decreasing amounts of saliva as tones grew farther from the one originally combined with meat powder; they did not treat the category as a logical bounded set of which stimuli were either members or non-members. Generalization gradients were not thought of as relevant to concept formation, however, perhaps because they violated all the classical view requirements.

This anomaly was first brought to the attention of psychology through work on color categories. Consider: is red hair as good an example of *red* as a red fire engine? Two anthropologists (Berlin & Kay 1969) had argued that there were a limited number of basic color terms in languages and that, while the boundaries of color categories fluctuated widely between languages and speakers, there was a great deal of agreement on which colors were the best examples of those terms. Rosch (1973) showed that the Dani of New Guinea, a people who do not have hue terms in their language, nevertheless remember best examples of color categories better than poor examples, and learn names for color categories more easily when those categories are structured around the universal best examples than when structured (unnaturally) around peripheral colors. Rosch suggested a model in which categories formed around perceptually, imaginally, or conceptually salient stimuli, then, by stimulus generalization, spread to other similar stimuli — without necessarily any analyzable criterial attributes, formalizable definitions, or definite boundaries. There is graded, rather than uniform, membership in such categories.

What of other than simple perceptual categories? Is a dentist's chair as good an example of chair as a dining room chair? An extensive research program established a core of empirical findings (Mervis & Rosch 1981; Rosch 1978; Rosch & Lloyd 1978). In the first place, all categories show gradients of membership; that is, subjects can easily, rapidly, and meaningfully rate how well a particular item fits their idea or image of its category. Gradient of membership judgments apply to the most diverse kinds of categories: perceptual categories such as *red*, semantic categories such as *furniture*, biological categories such as a *woman*, social categories such as *occupations*, political categories such as *democracy*, formal categories that have classical definitions such as *odd number*, and ad hoc goal derived categories such as *things to take out of the house in a fire*. (The reliability of such ratings, which varies with conditions, will be discussed further in Section 3).

Gradients of membership must be considered psychologically important because such measures have been shown to affect virtually every major method of study and measurement used in psychological research: (Note: unless otherwise indicated, the following studies are all reported or referenced in: Markman 1989; Mervis & Crisafi 1982; Mervis & Rosch 1981; Rosch 1973, 1978, 1987; Rosch & Lloyd 1978; or Smith & Medin 1981): *Learning*: Good examples of categories are learned by subjects in experiments and acquired naturalistically by children earlier than poor examples, and categories can be learned more easily when better examples are presented first — findings with implications for education. *Speed of processing*: The better an example is of its category, the more rapidly subjects can judge whether or not that item belongs to the category. This is important because reaction time is often considered the royal road for learning about mental processes. *Expectation*: When subjects are presented a category name in advance of making some speeded judgment about the category, performance is helped for good and hindered for bad members of the category. Called priming or set in psychology, this finding has been used to argue (not indisputably) that the mental representation of the category is in some way more like the better than the poorer exemplars. *Association*: When asked to list members of the category, subjects produce better examples earlier and more frequently than poorer examples. *Inference*: Subjects infer from more to less representative members of categories more readily than the reverse (for example, they judge that a robin, a good example of *bird*, is more likely to spread a disease to other birds than is a duck). The representativeness of items also influences judgments in formal logic tasks, such as syllogisms. *Probability judgment*s: probability is thought to be the basis of inductive inference and, thus, the basis of the way in which we learn about the world. Representativeness strongly influences probability judgments (Kahneman, Slovic & Tversky 1982). *Natural language indicators of graded structure*: Natural languages themselves contain various devices which acknowledge and point to graded structure such as hedge words like technically and really (Lakoff 1987; Rosch 1975). *Judgment of similarity*: Less good examples of categories are judged more similar to good examples than vice versa. This violates the way similarity is treated in logic, where similarity relations are symmetrical and reversible.

The above findings show how the graded internal structure of categories affects pragmatic considerations of the way people think and act. But what determines what items will be good examples (often called *prototypes*) of categories in the first place — i.e. how do real world pragmatic constraints serve to create the structure of categories? The following are some sources (see references previously listed):

Statistical central tendencies such as the mean (good examples of animals tend to be medium-sized) and the mode (frequently encountered items or attributes) play a large role in some categories. In a related phenomenon, items are deemed good that have the highest family resemblance (named after Wittgenstein) to other members of the category.

Ideals are potent sources of prototypes. Ideals may be stimuli that are made particularly salient by physiology (good colors, good forms), by social structure (president, teacher), or by formal structure (multiples of 10 in the decimal system). The extremes of attribute dimensions create ideals (the largest cities are judged most representative of *city*). Cultural ideals may be explicitly taught (as with *saints*). Ideals may be derived from goals (as in ideal foods to eat on a diet). Causal theories generate ideals (as with sequences that "look" random). And some ideal prototypes are abstractions that have never been encountered (as in families of random dot patterns).

Exemplars, particular real world examples that are encountered, can also become good example prototypes. These may be the items that are the first learned or, at the opposite pole, the most recently encountered, or they may be items made particularly salient because they are emotionally charged, vivid, concrete, meaningful, or interesting. In one theory, items that are most similar to the presently encountered one are recruited from memory to be ad hoc prototypes. The limiting case is the model in which all exemplars ever encountered are retained in memory to be matched to incoming items.

Given the profusion of means by which the world creates category structure, it is not surprising that a great deal of terminological and experimental confusion has resulted. For example, prototypes may be "disapproved" by limiting the term *prototype* to only one subtype and then showing that another subtype does better on some experimental task. Or the cutting philosophical and psychological implications of graded structure may be bypassed simply by re-defining graded structure as the probability of an item being classified as a member of the category. However, the issues dividing the classical view of categories from the graded structure prototype view is not simply one of whether categories are to be measured determinately or probabilistically nor of which particular modeling devices one uses. It is a deep question about how one wants to think about what categories really are — should it be in terms of formal, logical abstractions or non-formal, pragmatic, sensory, imagistic, real world interactions? (Barsalou 1999; Nunez & Freeman 1999; Rosch 1999).

2.2 Non-arbitrariness and coherence of categories

Where do categories and category systems come from in the first place? Why are chairs a different category from tables or sofas? Why does chair seem more like this object's real name than *piece of furniture*, *material object*, or *desk chair*? Why does the category *kangaroos weighing between 1.3 and 2.9 lbs.* seem neither basic, coherent, nor likely?

In the classical view, categories could just as well be arbitrary sets of attributes and, indeed, were just that in traditional laboratory concept learning tasks. These provided no clue to the ecological conditions of real world category evolution. Rosch, Mervis, Gray, Johnson & Boyes-Braem (1976) proposed that under natural conditions there is a great deal of relational structure between perceptions, actions, and life activities, and that categories form so as to maximally map that structure. For taxonomies of common objects, they demonstrated that there was a level of abstraction, which they called the *basic level*, at which the perceived parts and properties that we consider attributes of the object, the simple mental codability of the object in terms of an image, the motor movements involved in using the object, and the use of the object in daily life activities all came together in a maximally structured and coherent grouping. Thus form and function, often pitted against each other in experimental studies, are actually highly correlated in real world basic level categories.

Basic level names for objects (*chair, apple, piano*) appear to have linguistic priority (Rosch et al. 1976). This is the level at which objects are almost invariably named by both adults and children in free naming situations (of course, naming can always be manipulated by context). Developmentally, these are the first names used by children and the names used by adults to young children (as suggested by Roger Brown long ago). Markman (1989) has shown that the use of names for categories makes it much more likely that young children will sort categorically rather than thematically, suggesting that children may have a very general hypothesis linking language use and categorization. Regarding the historical linguistic issue of what categories are coded first in a language, there is evidence that American sign language, which has a restricted vocabulary for nouns, has single signs almost entirely and exclusively at the basic level (Rosch et al. 1976). From historical linguistics there is evidence that words often first refer to concrete nouns and bodily actions, later generalizing to abstractions.

There is some evidence that the basic level has perceptual priority with objects first recognized at this level, then either searched further perceptually to make subordinate classifications or explored conceptually to infer superordinates (Murphy & Smith 1982; Rosch et al. 1976). It would seem reasonable that basic levels are developmentally the first level of categorization made by children, however, this matter is highly controversial. Some experiments have shown that young children both learn artificial categories and that they sort and name objects in natural categories at the level which we are calling basic for adults (Mervis & Crisafi 1982). Other studies show that children may first develop child basic categories that are different from the adult form, and, in particular, that preverbal children may use more general groupings that adults (Mandler, Bauer & McDonough 1991). The concept of basic levels has also been extended to domains other than concrete objects — to events, personality traits, emotions, scripts, grammar, abstractions — all with attendant controversy (Rosch 1999).

Many of the controversies seem to be the result of taking basic level narrowly as though it meant some particular canonical categories or particular levels of abstraction. But basic levels should be expected to be different for young children and adults, and for peoples of different cultures. Categories must ultimately arise from life activities, and basic level categories could provide an entry to the study of basic level events and processes. What is important is to further investigate the process of category formation by which relations between perceptual, functional, and causal properties in concrete real-world events are both searched out by individual learners and homed in upon by the languages and cultures of the world to form maximally useful and meaningful categories.

3. Modeling problems and critiques of graded structure

Initial reactions to the new view of categorization consisted primarily of attempts to deal with the empirical data from graded structure research without changing one's idea of the "real nature" of categories as fundamentally classical (or at the very least as requiring some sort of essentialist, classical, mental representation structure mediating them).

3.1 Mathematical models

One question was simply how best to model graded structure effects — graded structure now *re-defined* as the probability of an item's being classified as a member of the category. Artificial categories were once again the stimuli but now constructed so as to mimic the graded structure of natural categories. The main issue was the level of abstraction and/or detail that need be assumed in the category representation (see Barsalou 1990; Neisser 1989; and Smith & Medin 1981, for references for the particular models cited): Extreme prototype-as-abstraction models (Homa, Reed, Posner) assert that only a summary representation preserving the central tendencies among category exemplars is necessary. Fairly extreme exemplar views (Brooks, Medin) argued that the memories for all individual exemplars are combined whenever a category judgment is made. Other investigators (Holyoke, Hayes-Roth) modeled the category representation in the form of a frequency distribution which preserves not only the central tendencies, but also some information about the shapes of the distribution and the extent of variability among exemplars. Still other investigators use abstractions of features rather than of prototypes: e.g. in the inclusive two-stage feature comparison model of Smith, Shoben, and Rips, matches of the new item to a category are first attempted on the basis of features that are *characteristic* of the category; if this fails, *defining* features are invoked (thus incorporating the classical view as a stage of processing). One popular exemplar model (the context-cue model of Medin and Schaffer) proposed that subjects compare a new item to all or some exemplars from each category, rather than to the prototypes only, and compute similarity of the new item to each of the retrieved exemplars individually. The popularity of this kind of modeling abated somewhat when it became apparent that the models could not be distinguished on the basis of empirical evidence since each model of storage is always presented with complementary processing assumptions which allow it to match any kind of experimental data (Barsalou 1990).

3.2 Critiques of graded structure

The critiques are largely based on the assumption (highly disputable — see Rosch 1999) that graded structure or prototypes must provide the same kind of philosophical object of knowledge, formal properties, and object of semantic reference that the classical view supposedly provided.

Formal semantic conditions. Can prototypes substitute for defining features in a formal semantic model that would account for logical and linguistic functions such as synonymy, contradiction, and conjunctive categories? In an influential tour de force, Osherson & Smith (1981) modeled prototype theory using Zadeh's system of fuzzy set logic in which conjunctive categories are computed by a maximization rule and showed that prototypes do not follow this rule; for example, *guppy* which is neither a very good example of the category *pet* nor of the category *fish* is an excellent example of the category *pet fish*. (This has become known as "the pet fish problem.") After several other demonstrations of the failure of Zadeh's fuzzy logic in this context, Osherson & Smith conclude that graded structure, while it may apply to the way category members are recognized, has nothing to do with the inherent logic of categories or the real meaning of category terms.

Graded structure effects are too universal. Graded structure effects are found in the most diverse kinds of categories including those such as *odd number* for which people agree there is a standard formal classical definition. This has been taken as a refutation of the importance, or even meaningfulness, of graded structure effects. (This may be the only case on record where the robustness of a finding is considered its downfall.) Again the logic seems to be that the classical definition is the real meaning of a term which, if present, invalidates all other possible meanings.

Core concept and processing heuristics. One solution offered to both of the above critiques is embodied in a class of models in which the actual meaning for category terms is a classical definition onto which is added a processing heuristic or identification procedure which accounts for graded structure effects (Osherson & Smith 1981). In this way odd number can "have" both a classical definition and a prototype. By this means, graded structure models are consigned the task of accounting for data, and the classical view, decoupled from any empirical referent, can fulfill unhampered its original philosophical (metaphysical?) mandate.

Context effects and the instability of graded structure. In the classical view, if an object of knowledge were to change with every whim of circumstance, it would not be an object of *knowledge*, and the *meaning* of a word must not change with conditions of its *use*. One of the great virtues of the criterial attribute assumption had been that the hypothesized criterial attributes were just what didn't change with context. If prototypes or other aspects of graded structure are to fulfill this function, they must be unaffected by context. However, the effects of context on graded structure are ubiquitous (Barsalou 1987) — just is would be predicted by pragmatics. Furthermore, people show perfectly good category effects, complete with graded structure, for ad hoc goal derived categories for which we surely would not want to posit pre-stored unchanging representations, (e.g. *things that might fall on one's head*).

One response to demonstrations that prototypes and graded structure do not fill the functions which criterial attributes fill in the classical view is to downgrade the importance of graded structure. Another might be to challenge classical essentialist assumptions. For example, perhaps category meaning and reference do not exist as such either in the culture or the mind. Barsalou (1987) suggests that categories are computed from other kinds of information anew "on-the-fly" in each situation — perhaps we should think of context effects as the flexibility not instability of graded structure.

On a more general level, in current cognitive science, there is a whole class of computer models known as connectionist (parallel distributed processing) models specifically designed to violate certain essentialist assumptions (see Johnson & Erneling 1997). Representation of a particular entity, such as a category, is modeled as a state of activation defined over the entire memory system rather than as an invariant component of memory retrieved from a particular location. Knowledge and word meanings are states of activation of the system; there is no question of invariant objects. On a more general level still is the suggestion of philosophers, notably Wittgenstein and his successors, that knowledge and language are not matters of referring to anything at all, but rather should be considered forms of life — thus suggesting a reworking of the entire classical view.

4. Categories as theories

Categories are actually theories, asserts this latest approach to categorization. Major proponents of the view are Medin (see Neisser 1989) in cognitive psychology; Carey (1985), Gopnik (Gopnik & Meltzoff 1997), and Keil (1989) in developmental psychology; and Lakoff (1987) in linguistics. The theories approach, a top-down view which appears to bring categorization into a broader context once again, lays claim to a number of contributions to the understanding of categories:

Critique of the use of the concept of similarity: Both prototype and exemplar models assume matches to a standard, based on similarity. Yet we have no adequate account of similarity. Models of similarity which use features are inadequate because assignment of weights to the features is always done outside the model; e.g. a zebra would be more similar to a barber poll than to a horse if *striped* was sufficiently weighted. In fact, Carey (1985) has found that young children classify a live human with a live worm rather than with a toy monkey, although the human and monkey have many more nameable common features. The argument is that it is children's developing biological theories which provide the basis for weighting attributes and perceiving similarities.

A critique of the concepts of attributes and features: Categorization research talks continuously of attributes and features, but what is to count as one? For example, the number of features that *plums* and *lawnmowers* have in common could be infinite: both are found in our solar system, both cannot hear well, etc. Most of the attributes used in the stimuli in artificial categories or listed by subjects for natural categories have the following (long acknowledged) problems: they are often definable only in relation to their category (we call parts of a chair *back* and *seat* because they are parts of a *chair*); they are themselves categories not primitives; and they are properly attributes of the category only if combined into the appropriate structures (the wings and feathers of a bird have to be properly assembled into a bird structure). The attributes that are seen in an object depend upon prior information about the object (subjects list different attributes for children's drawings if told they are drawn by city versus farm children). And finally, there are many experimental demonstrations that correlations of attributes may not be seen without appropriate causal theories that link them, and that illusory correlations may be seen when dictated by theory (see Nisbett & Ross 1980). In short, as in the case of similarity, a major building block for theories of categorization has been attacked. (But note also that no alternative theory has been offered).

A place within the "theory" theory of child development: As outlined by Gopnik & Meltzoff (1997), the theory theory is a general approach in which cognitive development in a given domain is seen as the successive replacement of one theory held by the child by another theory, much as in the Kuhnian view of scientific development. Categories as theories could become allied with this approach — although for the theory theory, interest in concepts tends to be from the point view of change in the child's (rather than the researcher's) theory of what a concept is.

A causal theory of natural kind terms: In contrast to the classical view of meaning, the philosopher Kripke (elaborated by Putnam — see Keil, 1989) has suggested that natural kind terms (*gold, skunk*) require a causal theory of meaning; items are named and identity of the category preserved by historical continuity, while experts discover the actual category attributes. Keil has discovered analogous causal theories in children who, while conceding that a coffee pot could be remade into a bird feeder, staunchly maintained that a de-sacked and repainted skunk would still be a skunk.

Theories can attempt to preserve the classical view of concepts and word meaning while also accounting for graded structure effects: A bachelor is by classical definition an unmarried man. Poor examples of the category (homosexuals, the pope, Tarzan) do not require us to posit fuzziness in the category itself; they are simply the result of the lack of fit between our folk theories (our idealized cognitive models) about bachelorhood and conditions in the world.

The classical view as a theory: Finally, the classical view itself may be considered a theory, a tenacious theory which, as we have seen, can survive much data. It is a theory which children develop; Keil calls it the characteristic to defining shift. Children who were once content to classify a man as an *uncle* or a weather conditions as *rain* on the basis of characteristic features now become little lawyers in their efforts to find defining features which will unequivocally determined borderline cases.

Is the theory of categories as theories a new claim of substance, or is it only a battle cry? On the one hand, it can come as a refreshing recognition of the larger context in which categorization always occurs. However, the theories view is remarkably silent on all positive issues one might expect it to address. What is meant by a theory? (Explicit statement that can be brought to consciousness? Any item of world knowledge? The complete dictionary and encyclopedia? Any expectation or habit? Any experimental context?) How does the theories view, beyond criticizing other accounts, itself account for similarity — a problem at least as old as the problem of universals? Likewise for the problem of attributes — given a theory, how are we to derive or predict attributes from it? (Note that although Gopnik & Meltzoff 1997, discuss in detail what theories are and are not in science, they do not address the above questions which arise in regard to categories as theories.)

It is hard to escape the impression that presently absolutely anything can count as a theory and that the word *theory* can be invoked as an explanation of any finding about similarity or attributes or categories. If perceptual constraints are in evidence, one talks of perceptual *theories* (and invokes evolution) — somewhat like the proliferation of *instincts* and *drives* in an earlier psychology. It is interesting that many of the arguments used to support a theory view (e.g. examples that require one to bring world knowledge into one's explanation) are the very kind of issue used in the Heideggerian phenomenological tradition to argue against theories and in support of the necessity of positing a non-theory based Background of habits and skills which underlies the categories and activities of human life. (Partly in response to some of these issues, a new event-based, as opposed to representation-based, approach to categorization may be in process — Barsalou 1999; Rosch 1999). Clearly, the theories view, and any subsequent approaches, have interesting challenges ahead of them.

5. Conclusion

We do categorization research from within our own category systems. Thus categorization necessarily involves, but is not encompassed by, each of the aspects and processes reviewed. However, from the pragmatic point of view, we need to broaden our vision of categorization even more than this. The categories we use are actually forms of life; they are our views embodied in customs, languages, individual mental activities, child-rearing, values, habits, and so on — how people, and other organisms, act and live. Hopefully, future research can reflect such a broadened perspective.

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Cerebral division of labour in verbal communication*

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> *"I know you believe you understand what you think I said, but I am not sure you realize that what you heard is not what I meant."* (Attributed to a Chairman of the U.S. Federal Reserve while addressing Congress.)

1. Introduction

Over the past 25 years, we have considerably advanced our knowledge of the cerebral processes involved in verbal communication. This knowledge, mostly derived from clinical observations of brain-damaged individuals and concordant with neuroimaging data, provides good reasons for studying the language system qua grammar independently of the pragmatics of verbal communication. Every domain of pragmatics involves probabilistic inference, which must be distinguished from necessary logical deduction and obligatory linguistic derivation. There is accumulating evidence of a neurofunctional division of labour in processing the linguistic and pragmatic components of verbal communication.

The cerebral representation of the language system, comprising phonology, morphology, syntax and semantics, has been extensively studied for over 140 years. These efforts have resulted in the identification of the perisylvian cortex and some subcortical structures in the left hemisphere as being involved in the representation and processing of what some linguists call a generative or sentence grammar. Such a grammar is acquired incidentally (by focusing on something other than what is internalized; e.g., on the meaning while internalizing the form, or on the acoustic properties of sounds while internalizing the articulatory and phonatory movements through proprioception), stored implicitly (its form is inferred from the systematic verbal behaviour of speakers but actually remains forever opaque to introspection), and used automatically, that is, without conscious control (Paradis 1994). Lesions in these left-hemisphere cerebral structures result in various forms of dysphasia, namely deficits in phonology, morphology, syntax and/or semantics.

*This chapter was written in 2001.

Not until the last couple of decades, did it become apparent that individuals with right-hemisphere damage exhibit verbal communication deficits that are qualitatively different, but equally — if not more — disabling. The deficits so far described are of a pragmatic nature, comprising difficulty with comprehension and/or production of affective prosody, indirect speech acts, metaphors, and connotative meanings in deriving the appropriate meaning of utterances. There are also deficits at the level of discourse, such as problems of cohesion and the inability to derive the gist of a story or the moral of a tale. As one can imagine, taking everything literally may have drastic consequences. In fact, it would appear that the incidence of divorce is much higher among individuals with right-hemisphere damage than among dysphasics.

2. Dyshyponoia

Whereas the term *dysphasia* (or *aphasia*) has come to be used to refer to linguistic impairments subsequent to focal lesions in specific areas of the left hemisphere, because of the recency (and hence comparative paucity) of studies of right-hemisphere verbal communication disorders, there was no term to refer to individuals with right-hemisphere communication deficits until the term *dyshyponoia*[1] was proposed to refer to impairments of linguistic pragmatics subsequent to right-hemisphere lesions (Paradis 1998); whether such lesions are focal or not remains to be determined empirically.

What we do know so far is that right-hemisphere damage causes problems with the interpretation of paralanguage, e.g.,

- emotional prosody;
- body language (pale, flushed, or sweaty skin; breath rhythm);
- gestures, gaze, facial expressions (eyebrow and mouth shape and/or movement);
- situational context (objects, events);
- shared knowledge (including general world knowledge);
- discourse context (inference, presupposition, implication), co-reference (synonyms, definite articles, pronouns), cohesive hinges, tense agreement, and serial order of sentences.

Pragmatic competency is thus the ability to make the appropriate linguistic and paralinguistic choices, given the context, the required effect (e.g., humour, sarcasm, implicit performative, metaphorical meaning, etc.), and the knowledge assumed to be shared with one's interlocutor. Individuals with dyshyponoia are unable to draw appropriate inferences (Duchêne 1999), leading to problems in interpreting the unspoken component of utterances. They are generally reported to tend to understand what is said rather than what is meant.

Patients with dyshyponoia therefore exhibit problems with metaphorical meaning, that is, meaning derived from the particular context in which an utterance is produced.

1. Derived from the Greek verb *ὑπονοώ* — to grasp what is implied though unspoken.

Because a word or expression used metaphorically takes its meaning from the particular circumstances in which it is uttered (i.e., the meaning is not intrinsic, as figurative meanings listed in standard dictionaries would be), it must be inferred from the contexts of use of the word or expression, and thus is difficult for dyshyponoiacs to derive.

Patients with dyshyponoia may have fewer problems with figurative meanings, that is, conventional metaphorically derived meanings (listed as such in dictionaries, sometimes as 'secondary' meanings, usually opposed to literal ones). Such conventional figurative meanings may be assumed to be listed in the speaker's mental lexicon; if such a meaning happens to be the most frequently used meaning of the word or expression, it may be considered to be the default case, and thus be retrievable by dyshyponoiacs more easily than nonce metaphorical meanings.

Connotative meanings, i.e., evoking qualities, feelings, and situations commonly associated with a word, either conventionally (language/culture-specific — e.g., the word *dog* may connote food, pet, danger, and insult, respectively in Korea, England, France, and the Arab World), or personally, as influenced by personal experience (e.g., the word cat may suggest a 'cuddly' or 'scratching and hissing' animal). These connotations are not listed as such in dictionaries, and since the content and strength of a given connotation will vary greatly among individuals, so will its resistance to right-hemisphere damage.

An utterance can have several meanings, depending on the particular context (e.g., 'his office is a tomb' could mean that it is dark, that it is cold and humid, that information will not leak out, that it is located in a windowless basement, or that an archeologist has set up his office in the tomb of Ramses II for the duration of his exploration). The difficulties may be compounded when multiple pragmatic dimensions apply to a single utterance (e.g., when a metaphor is used as irony, as when 'you are an angel' is addressed to a person refusing to do you a favour). It is therefore not surprising that individuals with dyshyponoia are often reported to have difficulty with humour and sarcasm in the form of metaphorical remarks.

3. Right-hemisphere involvement

Much about the way in which the right hemisphere subserves pragmatics remains to be determined. Both clinical and experimental evidence points to a cerebral division of labour concerning the treatment of linguistic versus pragmatic elements in verbal communication. But as to how the right hemisphere actually processes pragmatics, we are still nowhere close to anything like what we now know about how the left hemisphere processes implicit linguistic competence.

We need to ascertain whether all nonliteral meanings are equally susceptible to damage or whether various types of nonliteral interpretation form a hierarchy of vulnerability; whether different patients show preferential deterioration of different types of nonliteral meanings, thus pointing to the neurofunctional independence of these various aspects; and whether a patient's ability to make appropriate inferences varies as a function of the clues from which something must be inferred or the nature of what must be inferred. These are only some of the several dimensions of pragmatics that need to be investigated as we attempt to ascertain how pragmatic ability is represented and processed in the brain.

For instance, we do not yet know whether the various pragmatic deficits that have been reported are manifestations of an underlying unitary phenomenon (in which case all aspects should be simultaneously affected by brain damage); whether they represent a hierarchy of complexity and consequently of vulnerability to brain damage; or whether, like phonology and syntax in the left hemisphere, they represent neurofunctional modules, capable of double dissociation. If they are modular, we do not know whether each is subserved by individual dedicated neural substrates involving different cortical and/or subcortical structures. Nor do we know, on the other hand, whether the various pragmatic impairments result from a common underlying cause, and if so, what it is. There appears to be at least some hierarchy of complexity in that indirect speech acts seem to be easier than other types of nonliteral speech acts such as irony (Champagne 1999).

Some authors argue that pragmatics, unlike grammar, is not modular (Wilson & Sperber 1986) but relies on central cognitive processes (Kasher 1991). Pragmatic processes appear to be modular at least to the extent that they are specifically vulnerable to right-hemisphere damage, as opposed to the literal interpretation of sentences, which is vulnerable to lesions in specific left-hemisphere areas (Hirst, LeDoux & Stein 1984) and thus relies on particular neural substrates. Right-hemisphere-damaged patients have difficulties with the pragmatic component of indirect speech acts while left-hemisphere-damaged patients have difficulties with the linguistic component. Likewise, the production of lexical stress is preserved in patients with right-hemisphere damage (Behrens 1988); whereas patients with left-hemisphere damage perform worse than non-brain-damaged controls on comprehension and production of lexical stress, patients with right-hemisphere damage do not (Emmorey 1987; Gandour et al. 1988; Gandour et al. 1995; Moen & Sundet 1996).

Typically, individuals with right-brain damage do not exhibit deficits in phonology, morphology, syntax or semantics — the sentence meaning derivable from the lexical meanings of words and the underlying sentence structure — which are precisely the kinds of deficits usually exhibited by individuals with aphasia. The discourse impairments that do occur in aphasia are qualitatively different from impairments subsequent to focal right-hemisphere lesions. As summarized by Chantraine, Joanette & Cardebat (1998), the literature contains a number of observations about individuals with left-hemisphere damage, such as

- different word ratios among grammatical classes (for example, N/V ratios);
- reduced syntactic richness in terms of length, complexity and correctness;
- increased use of deictics, resulting in a more descriptive strategy when producing narratives;
- difficulties with the use of pronouns, leading to problems of reference;
- reduction in the number of lexical items, which impoverishes the narrative.

But these individuals have been shown to retain the ability to use pragmatic clues to infer a speaker's communicative intentions from paralanguage, situational context or general knowledge — precisely what is impaired in individuals with right-hemisphere damage. Even patients with global aphasia retain their comprehension of emotional prosody (Barrett et al. 1999), something that has often been reported to be unavailable to patients with right-hemisphere damage. (On the other hand, it is interesting to note that the right hemispheres of most split-brain patients do not show evidence of linguistic capacities of any kind; in the very few cases where they do, this is attributable to the presence of early right-brain damage; [2] Gazzaniga 2000.)

Access to denotative meaning is impaired subsequent to left-hemisphere lesions. Access to figurative or connotative meaning is impaired subsequent to right-hemisphere lesions. Semantics, in the sense of the sentence meaning derivable from the meanings of words and the relationships that obtain between them, such as theta-roles, is impaired subsequent to left-hemisphere lesions. Pragmatics, in the sense of the interpretation of the meaning of utterances on the basis of inferences about the situational and discourse contexts and general knowledge, is impaired subsequent to right-hemisphere lesions. These findings do not necessarily prove that literal meanings are represented in the left hemisphere and figurative meanings in the right; they may simply indicate that right-hemisphere inferencing processes are needed to realize that the default, literal, primary meaning arrived at by left-hemisphere-based linguistic competence is not appropriate to the context.

In a Japanese patient described by Sasanuma, Kamio & Kubota (1990), discourse markers (indicating emphasis or questions) were preserved in the context of omission of structural particles (indicating subject, object or topic). This may be a further indication of the dissociation between grammatical and pragmatic elements. Loew, Kegl & Poizner (1997) report the same pragmatics/grammar dissociation between sentence-level and discourse-level devices in American Sign Language.

Neuroimaging studies (Perani et al. 1996, 1998; Dehaene et al. 1997) show activation of right-hemisphere anatomical areas roughly homologous to the areas concurrently activated in the left hemisphere (frontal and temporal areas) while listening to short stories for comprehension, suggesting that both linguistic competence and pragmatic inference are used to understand stories. These studies also show greater activation in these particular right-hemisphere areas in the case of a weaker second language — which is not surprising, if we assume that increased reliance on pragmatics compensates for gaps in linguistic competence. Just as aphasic patients demonstrate the capacity to utilize extralinguistic cues

2. When brain damage is incurred in early childhood in an area that generally subserves a particular higher cognitive function, some re-organization takes place, and language may be in part subserved by surrounding areas or, to some extent, shift to the right hemisphere. In other words, the evidence shows that, unless forced by incapacitating injury to the classical language areas, the right hemisphere does not sustain the language system.

to discern the contextually conveyed intended meaning of implicit speech acts (Wilcox et al. 1978), speakers of a second, weaker language (whether brain-damaged or not) are able to compensate for their lack of linguistic competence by relying on pragmatic cues. In fact, this is what unilingual genetic dysphasics do (Paradis & Gopnik 1997). In a recent neuropsychological experiment, 'overly literal and inflexible' patients with right-hemisphere damage had difficulty with the pragmatic and figurative aspects of language; by contrast, like controls, they experienced virtually no impairment on the Western Aphasia Battery measures (Bryan & Hale 2001).

We thus have ample evidence of a double neurofunctional dissociation depending on which hemisphere is affected. But we do not know the actual source of the deficits reported subsequent to right-hemisphere damage. Whereas site and size of lesion are routinely reported in aphasia studies, they seldom are in right-hemisphere damage reports. When they are, they are not correlated with individual patients, as authors report only group results. There nevertheless appears to be some modularization within the right hemisphere, at least to the extent that affective prosody has been isolated in some patients with right frontal lobe damage (Ross 1981 1984; Shapiro & Danly 1985; Dykstra et al. 1994; Ross et al. 1997). Stemmer & Joanette (1998) also report that, among right-brain-damaged individuals, confabulation, embellishments and unnecessary repetitive details are more frequent in individuals with *anterior* lesions.

One may conceive of the right hemisphere as being functionally organized either similarly to the left hemisphere, namely in a modular fashion, with various specific areas being dedicated to specific functions, *or* in a fundamentally different way, reflecting a, more global and holistic and hence less analytic mode of functioning. It would then follow that the various aspects of pragmatic abilities might be represented more diffusely in the right hemisphere than the various aspects of linguistic competence are in the left hemisphere. But we need anatomoclinical correlations of specific symptoms with particular circumscribed lesion sites before we can form an idea of how the various relevant dimensions of pragmatic phenomena are organized. All we can say at the moment with some confidence is that circumscribed areas of the left hemisphere play a role in the representation and processing of implicit linguistic competence (or sentence grammar), and that yet-to-be-specified areas of the right hemisphere play a role in the representation and processing of pragmatic abilities.

This view is not universally accepted as yet. For example, Bara, Tirassa & Zettin (1997) claim to have verified on a population of closed-head injury (CHI) patients their theory that, in sharp contrast with the previous literature, there is no difference between the comprehension of direct and indirect speech acts. In fact, their data do not speak to the issue of localization of pragmatic functions such as indirect speech acts, since only three out of thirteen patients are reported to have unilateral right-hemisphere damage (note that three patients have unilateral *left*-hemisphere damage, the other seven suffered bilateral damage).

As the authors themselves point out, CHI implies a constellation of symptoms that are typically related to diffuse tissular or axonal damage resulting in the impairment of many different subsystems — bilaterally. As is common with CHI patients, the site of damage tended to be either diffuse or to affect different cerebral regions in different patients (frontal, fronto-temporal, fronto-parietal, temporal, occipital). Some of these lesion sites would not be expected to result in deficits of either a grammatical or a pragmatic nature (e.g., bilateral occipital lobe damage). Thus, it may not be so surprising that, contrary to all other studies of right-hemisphere-damaged patients, the authors found no difference between direct and indirect speech acts. Moreover, the indirect speech acts in question were of the most conventional type, and hence very likely to involve the default meaning of these expressions, a very relevant dimension that was not controlled for. In addition, the time taken to complete the protocol by subjects in the CHI and control groups was judged to be comparable and hence not worth reporting, even though it varied by up to 33% (10 minutes out of 30 minutes). It is therefore premature to conclude, as the authors repeatedly do, that there is no difference between the comprehension of direct and indirect speech acts. Moreover, the fact that none of the subjects made a single error in understanding speech acts, either direct or indirect, may demonstrate that their comprehension was unimpaired, but it does not address the issue of a possible dissociation. Thus, these findings do not "contradict all previous neuropsychological research" (Bara, Tirassa & Zettin 1997: 30) — they are simply not relevant to the issue.

4. Implicit pragmatic competence and metapragmatic knowledge

Linguistic *competence* has been demonstrated to be implicit (except for some aspects of the lexicon, such as the sounds of words, which we recognize, and their referential meanings, which we know and which are therefore explicit), but nobody has yet demonstrated (or even investigated) whether pragmatic *ability* is implicit or explicit. It is probably both — some of it is implicit (and we would therefore refer to these aspects as pragmatic competence), and some of it is explicit (and we would refer to those aspects as metapragmatic knowledge). It is obvious that some cognitive computation takes place. What is less obvious is whether that computation is conscious or not. Which aspects are implicit and which explicit has not yet been investigated in detail. To be sure, some clues, such as pupil size (Hess 1965), must be implicit, since they are known only to specialists, and yet have been shown to have an impact on our interpretation of an interlocutor's state of mind and communicative intentions (though the speaker is just as unaware of producing those clues as the listener is of making use of them). We constantly emit signals of which we are not aware and over which we have no control when engaged in the give-and-take of communication (Watzlawick 1976). In other cases, though, such as the interpretation of proverbs or metaphors, the mental processes may be more explicit, because such things may be taught in school, for example. However, much interpretation of indirect speech acts is so instantaneous and evidenced at such an early age that it appears *prima facie* to be implicit.

Even though the description of right-hemisphere language deficits has not yet reached the level of precision attained in describing aphasic left-hemisphere deficits, to the extent that pragmatic competence relies on implicit cultural conventions, some pragmatic automatisms likely rely on procedural memory, and hence may be expected to be subserved by specific cortical areas in the right hemisphere. We may thus expect that those aspects of pragmatic capacity that are implicit (i.e., pragmatic competence) are subserved by circumscribed areas of the right hemisphere whereas those that are explicit (metapragmatic knowledge) are bilaterally distributed over extensive areas and involve various mechanisms of conscious reasoning.

An important dimension that needs to be controlled in experiments is precisely the conventionality of nonliteral meanings. The default interpretation of a word or expression as literal or nonliteral depends on its degree of conventionality. Some figurative meanings may be lexicalized. These meanings may occur more frequently than their literal counterparts, and hence constitute the default case, that is, the statistically most likely meaning of the word or expression; they would therefore require an unusual context to be interpreted literally. However, the default interpretation of the words used in most nonconventional metaphors is the literal one. Stemmer, Giroux & Joanette (1994) showed that dyshyponoiacs had more problems with nonconventional indirect requests than with other nonliteral expressions. Conventional metaphors and idiomatic expressions, may, therefore, not be as vulnerable as novel metaphors and nonconventional indirect speech acts (e.g., 'Is there any salt on the table?', as opposed to 'Can you pass me the salt?'). If we assume, as we shall discuss below, that what causes the right hemisphere to be involved is the need in unusual circumstances to infer a meaning other than the one provided by the grammar, then when a common indirect speech act or frozen metaphor has turned into an idiomatic expression and thus become the default interpretation, it is the literal interpretation that needs a specific context in order to be selected. Hence, with right-hemisphere damage, the figurative meaning, in such cases will be readily available, because it has been lexicalized and thus become part of the left-hemisphere-based system.

Another dimension that may have to be considered is the transparent/opaque nature of indirect speech acts, from 'It's getting cold in here' as a request to shut the window (opaque: no reference to 'shut' or 'window') to 'Do you know what time it is?' as a request for the time (transparent).

Finally, just as not all non-canonical sentence constructions are equally difficult for agrammatic patients (depending on the number of steps by which they deviate from the canonical form), indirect speech acts may not be equally difficult to understand, depending on the number of features that distance them from the default interpretation (e.g., unconventionality, opacity, and compounding of such features, as discussed above).

After Lenneberg's (1967) influential proposal that both hemispheres were equipotential in infancy, and that during the first two years of life cerebral dominance is not yet established, it was generally assumed that language lateralizes to the left hemisphere over the years, becoming the province of the left hemisphere alone by puberty. The dominance phenomenon was thought to come about through a progressive decrease in the involvement of the right hemisphere. Goodglass (1978) suggested that, at the early stages of language acquisition, neurons are recruited bilaterally; in the course of language development, however, the more compact, faster systems in the left hemisphere survive, while the slower, less efficient components of the right hemisphere's neural network drop out of language processing. In fact, there is no evidence that grammar is ever subserved by the right hemisphere in children. In early childhood, most verbal communication does not contain much grammar, relying more on pragmatic aspects of language use and an increasing number of lexical items. During this time, children's grammars develop more slowly than their ability to understand utterances in context (Bloom 1974), underscoring their reliance on context in verbal communication. It is not surprising that, before the age of three, a child who suffers symptoms subsequent to either right- or left-brain damage will display undifferentiated mutism. In the absence of right-hemisphere pragmatic support, the left hemisphere's labile incipient grammar is insufficient to communicate verbally. Before the age of two, there is no grammar (in either hemisphere). Grammar does not emerge until two words are put together in a systematic relationship. When the first rudiments of grammar are internalized, they are processed by the left hemisphere right from the start. The right hemisphere does not play any role in the incipient grammar, though it does play an important one in supporting pragmatic aspects of language use. Indeed, implicit pragmatic competence is phylogenetically and ontogenetically prior to implicit linguistic competence. It is part of what Lamendella (1977) called the general communicative system.

5. Inference

One thing seems reasonably well established: All domains of pragmatics, as diverse as they may seem, share a common property, the use of inference. Not only is there ample evidence that dyshyponoiacs have deficits in discourse-level skills such as inferencing (Joanette et al. 1986; Leonard & Baum 1998), but all tasks associated with deficits in dyshyponoia have an element of inference as a component. For example, one must infer from paralanguage that the speaker is happy or angry, or from some context that an utterance is meant literally or not; the gist of a story must be inferred from the various pieces of the tale, etc. In addition, there are two dimensions in every inference: The nature of the sources one infers *from* (facts, general knowledge, discourse, paralanguage) and the nature of *what* is inferred (e.g., mental states of one's interlocutor vs. facts). Whether these dimensions have a different impact on comprehension and whether they are dissociable or hierarchically organized also needs to be investigated.

One might argue that, rather than an inferential deficit, individuals with dyshyponoia suffer from a plausibility matrix deficiency that leads to difficulty in rejecting events whose probability of occurrence *according to the context* is low. This proposal assumes an inability to infer from the context that a particular event is implausible. In other words, the ability to process the content of discourse according to the context in which it occurs requires inference — an inference as to the probability, plausibility, likelihood, or near-certainty that a particular meaning is intended.

Whereas it is true that inferences must *always* be drawn in order to derive the meaning of any utterance, whether literal or not (Bara et al. 1997), the evidence accumulated so far strongly suggests that when the right-hemisphere inferencing capacity is impaired, patients rely on the default literal interpretation provided by their intact left hemisphere. A direct or literal speech act is one of which the meaning is entirely specified by the grammar; that is, the meaning of the sentence generated by implicit linguistic competence is not altered by the context. Of course, in normal communicative situations, context must be checked if only to decide whether the interpretation needs to be modified, or whether the context favors (or even forces) a literal interpretation. Right-hemisphere-damaged patients, who have access only to implicit linguistic competence, have thus no choice and can only access the purely semantic interpretation, i.e., the meaning derived from the lexical meanings of the words and the underlying structure of the sentence. This will be appropriate only in certain restricted contexts (i.e., when a literal illocutionary act is intended).

Some researchers have reported that individuals with right-hemisphere damage were able to make some inferences. But the inferences that they seem not to have problems with are of a different kind: They rely on logical or purely linguistic premises, not on pragmatic contexts (which are contingent rather than necessary or obligatory). A number of considerations must be taken into account here before we throw out the hypothetical baby with the theoretical bathwater. We must distinguish between different types of inference: (1) logical deduction (including syllogisms and mathematical operations); (2) obligatory linguistic derivation (that is, semantics, the derivation of meaning from the lexical meanings of words and the underlying sentence structure); and (3) probabilistic pragmatic inference. The first two are necessary, while the third is contingent upon the context or circumstances of its use. A logical deduction is true or false under any circumstances, irrespective of context; a linguistic derivation is obligatory in accordance with the rules of each particular language and does not admit of shading; a pragmatic inference, on the other hand, is based on a set of weighted probabilities depending on various contexts. Individuals with right-hemisphere damage seem able to draw conclusions from logical and linguistic rules, but not to infer from among choices that are not absolutely obligatory. It is interesting that Osherson et al. (1998) have identified distinct brain loci in deductive versus probabilistic reasoning, as measured by regional cerebral blood flow.

In addition to their necessary/contingent dimensions, pragmatic inferences may differ in terms of the nature of the processes involved, whether implicit or explicit; these engage different neural substrates and hence are dissociable by pathology, depending on which cerebral mechanism is lesioned. In the case of procedural memory, the cerebellum and basal ganglia, in particular the striatum, are involved; for declarative memory, the hippocampal system, parahippocampal gyrus, and anterior cingulum are involved. It is thus not surprising that individuals with right-hemisphere damage should be able to make conscious logical deductions but not implicit pragmatic inferences.

Given the numerous dimensions, we are inclined to agree with Stemmer & Schönle's (2000) suggestion that it is unlikely that neuropragmatics is linked to a simple psychological or physiological mechanism and that the way the brain and mind process language involves a delicate interplay of various mechanisms.

6. The legitimacy of sentence grammars

The legitimacy of (context-independent) sentence grammar has not gone unchallenged. It has been increasingly argued over the years that generative grammars do not account for many of the phenomena that are involved in sentence interpretation (Lakoff 1974; Tyler 1978; Grace 1987). Many linguists have pointed out that, in normal language use, the interpretation of utterances requires not only a sentence grammar to derive the literal meaning of each sentence, but also a discourse grammar, comprising presuppositions and inferences, and in general all phenomena that are dependent on discourse context (anaphora, cataphora, sequence of tenses, cohesion, etc.). Since the normal use of language involves sentences uttered in context and deriving their meaning in part from that context, some researchers have asked whether there is any justification for positing a linguistics (that is, the study of sentence grammar) outside of pragmatics (the study of utterances in context).

Tyler (1978), for example, argued that "the initial error in linguistic analysis arises from abstracting the system of linguistic signs from their context and treating them as independent formal entities" (p. 461). According to him, pragmatics should have a constitutive role in semantics. Semantics, consisting of the relation of signs to things (reference), should not be independent of contexts of use. Today, the neurofunctional evidence argues in favour of a distinction between semantics — the meaning derivable from the meanings of words and the underlying grammar — on one hand, and pragmatics — the meaning inferred on the basis of the context in which the utterance is produced — on the other.

Some linguists have attempted to incorporate aspects of pragmatics into structural trees (Ross 1970; McCawley 1973; Sadock 1974; Parisi & Antinucci 1976), but without much success. The tendency among many contemporary European linguists (van Dijk 1981; Stickel 1983; Contini-Morava 1989; Davis & Taylor 1990) has been to abandon linguistics for pragmatics, in particular for the study of the discourse rules, speech acts, and paralinguistic phenomena on which the interpretation of sentences is based.

Among others, Lakoff (1974) argued that "the *form* of language cannot be studied independently of its [communicative] *function*" and that "the form of sentences is not independent of the *meanings* that they convey in *context*" (p. 177). The second statement is certainly true, but it does not entail the first. Even though the interpretation of a sentence requires consideration of the context of its use, the form of the sentence can nevertheless be studied independently of its function. In fact, this is precisely what the left hemisphere seems to do, while the right hemisphere must then decide how to interpret the utterance, given its intended or perceived function.

Lakoff further claims that "linguistic rules cannot be taken as having the function of distinguishing grammatical from ungrammatical sentences; grammar must also specify the *conditions* under which sentences can be *appropriately* used" (Lakoff 1974: 159, [his emphasis]). The left-hemisphere-based linguistic competence (grammar) is only a set of available choices. It does not specify the conditions under which sentences can be appropriately used. Right-hemisphere-based pragmatics does that for you. If I may tax the reader's right hemisphere with a metaphor, the grammar may be equated with the possible ways of getting from city A to City B. There are a number of routes — fast but boring highways or slow, scenic country roads; you can take a bus, or a train, or a taxi, or drive your own car. But the set of possibilities is independent of your decision, made on the basis of expense, time, and other relevant parameters, as to which route is most appropriate for a given purpose within a specific set of circumstances, although your decision is constrained by what is available. In other words, pragmatics is constrained by the grammar, which itself is independent of pragmatics. Pragmatic considerations will stipulate which of the various possible meanings is appropriate to the specific situation, and even give the sentence a meaning it has never had before. This pragmatic creativity is the contextual counterpart to Chomsky's notion of linguistic creativity within context-independent grammar — the ability to understand the literal meaning of a sentence never heard before. The choice of intonational stress, verbal mood, or an explicit performative verb, constitutes the selection, given the context, of the most appropriate form from among those provided by the language system. Pragmatics does not alter the grammar; it only selects from among availabilities.

Lakoff also maintains: "I don't think that one can in general say that sentences in isolation are grammatical or not" (Lakoff 1974: 155). Granted, grammatical sentences may be inappropriate in a given context, but they are nevertheless grammatical, that is, well-formed with respect to the normative linguistic system of the language. The full meaning of an utterance is inferred from both text and context, but the derivation of the meaning from the text, that is, from sentences, is obligatory, determined by lexical meaning and underlying (implicit) morphosyntactic rules. The meaning inferred from context is contingent upon the circumstances in which the text is used.

One quote from Lakoff typifies the claims in favour of a unitary grammar-cum-pragmatics: "Grammatical rules (e.g., sequence of tense rules) are subject to pragmatic constraints" (Lakoff 1974: 157). In fact, sequence of tenses is governed primarily by the grammar, and only secondarily by pragmatic concerns. Consider the sentence, 'It became apparent that individuals with right-hemisphere lesions exhibit verbal communication deficits'. The main verb is in the past (*became*), while the subordinate verb is in the present (*exhibit*). In French, the grammatical sequence of tense rule demands that the past be used in the subordinate clause as well, even though the event referred to is true today, whereas in English, *to refer to the same pragmatic reality*, the *present* is used. The pragmatics (like the rest of the encoded message) is filtered by the grammar. Pragmatic constraints, like all of the nonlinguistic cognitive notions that shape the message, such as the selection of which language to use, what register, what to talk about and whether to say it directly or through an indirect speech act, are not constraints on *the form* of the grammar. They are constraints on *selection* from among available rules, not on the structure of the rule.

Neurolinguistic evidence strongly suggests that rules (i.e., implicit computational procedures) are one thing: they belong to the domain of linguistic competence, which is the province of the left hemisphere. The selection of the appropriate rule in the given context is another thing entirely; it belongs to the pragmatic faculty, which is in large part the province of the right hemisphere (and possibly to some extent the frontal lobes), and in any case outside of the grammar itself. Note that the neurofunctional independence of the grammar from pragmatics is not dependent on a right/left-hemisphere functional dichotomy. The extent and nature of the right-hemisphere-dependence of pragmatic aspects of the natural use of language are empirical questions that necessitate much further investigation. But the fact that grammar can be available in the absence of pragmatics and vice versa in brain-damaged populations is evidence that the two are individually isolable, regardless of the localization of their respective neural substrates.

We must certainly agree with Lakoff (1974: 167) that "the role of context […] is at least as important as the role of literal meaning", but recent evidence points to the independence of pragmatics from linguistics, when the latter is narrowly defined as the study of sentence grammar, as represented in specific areas of the left hemisphere. The form of sentences is not independent of the meanings that they convey in context. The context (sociolinguistic or otherwise) influences the *choice* of available forms in the grammar (though the context does not modify the form — it can only select from among existing forms). The appropriate form for the occasion (an active, passive, topicalized subject or object construction depending on the emphasis one wishes to place on the agent, action, or object) is selected in the same manner as is language A over language B, or the contents of the message one wishes to verbalize. All these elements are extrinsic to the internal structure of the grammar, but active in the selection of a direct or indirect speech act, literal or figurative expression, degree of politeness, etc. Some of these extralinguistic decisions must be just as implicit as the grammatical operations themselves, but others may be conscious and deliberate.

I have argued that (context-independent) sentence grammar is theoretically separable from other aspects of sentence interpretation in normal language use because it has been shown to be doubly dissociated from them neurofunctionally. The dissociation holds even between linguistic and pragmatic gestural systems in American Sign Language users (Corina et al. 1992; Emmorey et al. 1995; Hickok et al. 1999). Even though sentence grammars are not sufficient to account for the interpretation of sentences in natural language use, there nevertheless appears to be a good theory-external justification for studying the structure of words, phrases and sentences in isolation, given that they are selectively impaired in dysphasia but not in dyshyponoia. We must thus distinguish language (in the sense of implicit linguistic competence or sentence grammar) from verbal communication, which, in addition, includes pragmatic abilities.

In a similar vein, even though in her epistemological model both semantic and pragmatic structures are made up of similar cognitive material, Bates (1976) asked whether pragmatics can still be considered a separate area of language science. Her answer was, "I think it can" (p. 353). It now appears that this is what the brain actually does. As Bates suggested, pragmatic and semantic structures constitute separate functional processes at any moment of speaking.

There is thus a sound rationale for distinguishing between the linguistic construct *sentence* and the pragmatic construct *utterance*. The former is independent of context and its semantic interpretation can be derived from the meaning of its words and its underlying grammatical structure; the meaning of the latter requires, in addition, inferences from the various contexts of its use (situational, discourse, general knowledge). The sentence component of the utterance is compromised in dysphasia (as is, in some forms of dysphasia, the literal meaning of words). The inferential component is compromised in dyshyponoia (as are, in some forms of dyshyponoia, the nonliteral meanings of words or expressions — note that selection of the figurative meaning of a word depends on inferences from the context and that, in isolation, the figurative meaning is a secondary one, usually derived by a metaphor based on some aspect of the literal meaning).

7. Semantics and pragmatics in the interpretation of an utterance

For purposes of interpreting an utterance, both grammar and pragmatics are necessary and neither is sufficient. Both have a constitutive role in the interpretation of the meaning of an utterance. But this is not to say that they cannot be dissociated for purposes of analysis. Verbal communication makes simultaneous use of both implicit linguistic competence and implicit pragmatic competence, each subserved by its own neural substrate and selectively isolable by pathology. Some left-hemisphere-damaged patients understand the (unspoken) pragmatic component of the meaning of an utterance, though not the meaning of the actual sentence, and some right-hemisphere-damaged patients are able to derive the meaning of the sentence (its 'grammatical' or 'propositional' component) but are unable to interpret the (unspoken) meaning of the utterance (its 'pragmatic' component and 'illocutionary force').

Briefly, language as an abstract and formal system is the linguist's attempt at a description, as detailed and complete as possible, of the observed regularities in the structure and use of speech sounds (phonology), inflections (morphology), relationships between words, as sometimes marked by word order (syntax), and the meanings of words (lemmas, or their lexical semantic and grammatical properties). This is what we call the (sentence) grammar. Speakers possess a system that, whatever its actual neurophysiological representation, can be described as a grammar, and which is generally represented in the perisylvian area of the left hemisphere in about 95% to 98% of right-handers. They also possess a system that is referred to as pragmatic capacity (the object of investigation of pragmatics or some specific aspects thereof, as must be empirically demonstrated) that contributes inferences from the situational and discourse contexts and general knowledge to the interpretation of the utterance.

The brain treats semantics not as a relation of signs to things, but of linguistic symbols to mental representations. These representations correspond to the most general characteristics of the class of referents that led to their acquisition. Thus, the meaning of a word does not correspond exactly to any specific referent but to the most generic definition, such as is generally found in dictionaries (i.e., the general meaning in the absence of a constraining context that would force another interpretation). Pragmatics provides the specific meaning, given a reference in time, place, and other contexts. A word does not correspond to a simple referent but to a mental representation of a prototype that can refer to any member of a class of referents, should a context specify a set of appropriate characteristics. In the case of a metaphor, only a portion of the meaning — some property of the default literal referent relevant to the situation — is selected.

While it is true that the derivation of the meaning of an utterance rests equally on grammatical and pragmatic clues, it is also true that implicit linguistic competence functions independently of pragmatic competence, and that the two, dealing with the said and the unsaid respectively, in parallel, conspire to arrive at the intended meaning (or what is perceived as the intended meaning). Semantics and pragmatics are independent in the way that phonology and syntax are independent. Each has its own underlying computational procedures (or implicit modus operandi) which differ in their objects and, to a great extent, in their internal structure — and yet both are necessarily used in concert, in every utterance. There is no spoken utterance without phonology, morphosyntax, or context. (Single-word utterances may be argued to have no syntax, but they must nevertheless contain phonological, morphological, and lexical semantic features and must be interpreted in light of contextual features.) The linguistic interpretation provides the semantics; inferences from the various contexts provide the pragmatics. Individuals with right-hemisphere damage may be capable of processing semantic but not pragmatic presuppositions.

Bates (1976: 3) rightly argues that a sentence such as 'Cats have nine lives' is almost entirely interpretable within a syntactic-semantic system, but that a sentence such as 'Yeah, I feel like that too' relies heavily upon use in a given context if it is to be understood. Both in fact are interpretable semantically but both need a context to arrive at a complete meaning. Semantic meaning is underspecified. The pragmatic component of meaning is required to provide the exact referents and the illocutionary force of each utterance. In the case of the second quoted utterance, the interpretation derived is less precise, though perfectly meaningful and understandable (with a greater degree of imprecision) in the absence of nonlinguistic context, i.e., that someone agrees that s/he shares someone else's feeling that was previously mentioned — although one does not know who the actual person is or the nature of the feeling. But the sentence is meaningful, even though imprecise. And this is what we may expect an individual with specific right-hemisphere damage to understand, even when the sentence is uttered in a normally constraining context.

Let us assume, following Kasher (1991: 579), that pragmatic competence "is involved in producing the integrated understanding of what has been said in a given context of utterance, as a function of the presumed linguistic interpretation of what has been said and additional information with respect to the intentional activity under consideration". If linguistic interpretation relies on left-hemisphere processing and the information from which the unspoken intentional activity is derived relies on right-hemisphere processing, we may also suspect that at least the language-specific pragmatic conventions from which the unspoken meaning is inferred could be selectively or differentially affected when right-hemisphere-damaged bilingual patients use one of their languages, in the same way as the grammar of one or the other language system has been shown to be selectively or differentially vulnerable, for a variety of reasons (Paradis 1977, 1989, 2001). Just as many concepts are shaped and refined by language-specific constraints, pragmatic capacity is shaped by culture-specific implicit pragmatic conventions. Thus, a speaker of German will implicitly infer a particular meaning from some specific nonverbal behaviour accompanying an utterance that is different from the meaning inferred under the same circumstances by a speaker of English or French. Both what Thomas (1983) has called 'pragmalinguistic' (i.e., highly conventionalized usage) and 'sociopragmatic' (i.e., involving the speaker's culturally determined system of beliefs) elements have language/culture-specific components sufficiently cross-culturally diverse that they may cause failure to communicate when not fully mastered in L2 (Thomas 1983). Hence, these pragmatic aspects associated with different languages, like aspects of the language subsystems proper, may be expected to be dissociable by pathology in bilingual patients.

Gibbs (1999) argues against the view that a distinction exists between what speakers say and what they mean in context, because pragmatics has a fundamental role in determining both what speakers say and what they implicate; he suggests that there may not be any principled distinction between sentence meaning and speaker meaning. He proposes that there is no sentence meaning without recourse to what he calls the primary pragmatic knowledge used to implicate. In other words, there cannot be a purely semantic derivation of the meaning of a sentence. Granted, the purely linguistic-semantic meaning of a sentence may sometimes be quite vague and need amplification from the context in which it is uttered. But the sentence still has a default semantic meaning, however imprecise. Contextual information is indeed necessary to resolve ambiguity and fix indexical references of time, person and place, and thus to understand what speakers actually mean. Nevertheless, what speakers say does have a context-independent, albeit imprecise, semantic meaning comprehensible by all native speakers. In fact, literal meaning is widely assumed, even by those who seem to deny its existence. Kasher (1991: 396), for instance, refers to "the literal meaning of expressions" beyond which the speaker–hearer needs to go in order to interpret sentences in contexts of their use, so as to derive the intended meaning of metaphors, sarcasm, and indirect speech acts (p. 395). This constitutes a justification for the distinction between *sentence* (with its literal meaning) and *utterance* (the use of asentence in context). It would even appear that the output of the linguistic module (i.e., the sentence) serves as input to the pragmatic module which, in view of the various available contexts, computes the probability of the various possible meanings and outputs the most plausible one: subjects process literal stimuli faster than nonliteral stimuli (Champagne 1999).

Both primary and secondary pragmatic information constitute *pragmatic* information on the basis of which an interpretation is inferred. Nothing is gained by, on the one hand, lumping together as a single construct primary pragmatics plus what people actually say (the sentence), and, on the other hand, everything covered by 'secondary' pragmatics. These two elements, namely semantics plus primary pragmatics vs. secondary pragmatics, do not seem to form natural classes. The division between what is actually said (and its meaning in the absence of any inference beyond semantics) and what is meant (which comprises not only primary and secondary pragmatic aspects but a much more complex web of intervening factors to infer from and to infer about) seems more categorical. Primary and secondary pragmatic knowledge (avowedly difficult to separate on the basis of principled criteria — Gibbs 1999: 473) are arguably different aspects rooted in different sources of inference (e.g., "knowledge that is widely shared across contexts" and "knowledge that is specific to a particular discourse", Gibbs 1999: 476). Nevertheless both are pragmatic in nature, unlike linguistic-semantic meaning, which is of a different nature (i.e., linguistic, non-probabilistic). Some pragmatic aspects may be more salient and thus more immediately usable in inferring what speakers mean. These aspects should be less vulnerable to insult than less widely available information that must be specifically recognized in a given situation before one can infer what a speaker is implicating. However, these are quantitative differences, whereas the difference between sentence meaning and any kind of pragmatic meaning is qualitative; not only does the latter depend on context, but the two kinds have been shown to be doubly dissociable neurofunctionally.

Like the "traditional view of pragmatics in figurative understanding", the "new view on the pragmatics of what is said" (Gibbs 1999: 477) is far too simplistic. Primary pragmatic aspects are (only) one step removed from what is actually said and processed by implicit linguistic competence. There are many possible further steps, whether processed sequentially or in parallel, depending, as discussed earlier, on the opacity, concreteness, frequency, metaphorhood, and indirectness of the utterance, all of which may be organized either hierarchically or modularly. Dennis & Barnes (2000) conclude from their analysis of speech acts after left or right focal injury in childhood that semantic competence is indirectly, but not directly, relevant to speech act production, in keeping with theories of pragmatics in which sentence and discourse grammar are independent. Kuperberg et al. (2000) have identified distinct neural substrates for pragmatic and semantic processing of spoken sentences.

8. Language vs. verbal communication: What's in a name?

The answer to the question, "are pragmatic aspects of communication a component of language or independent from it?" (Joanette & Ansaldo 1999: 530), depends on what one means by 'language'. If by language one means verbal communication, then the answer is that pragmatic factors are part of it. If by language one means the language system, qua grammar or implicit linguistic competence, the answer is that they are not. Given that 'language' has traditionally been used to mean the language system, as studied by linguists, the term 'verbal communication'[3] is preferable when referring to the use of language in context or normal discourse, which includes the intentions of the locutor as well as other aspects of pragmatics.

Joanette & Ansaldo (1999) propose that the term 'aphasia' be used to refer to pragmatic deficits consequent upon right-hemisphere damage in right-handers. Given that language deficits resulting from focal left-hemisphere damage (traditional aphasias) are qualitatively different and isolable from deficits in verbal communication consequent upon right-hemisphere damage, the latter would better be called 'dyshyponoia'. There is nothing but confusion to be gained by lumping together two types of verbal communication deficits that are qualitatively different and generally result from lesions in opposite cerebral hemispheres. In fact, Frederiksen & Stemmer (1993) and Stemmer & Joanette (1998) report that, *in contrast to aphasic patients*, right-hemisphere-damaged patients were not able to reconcile two episodes in a text to construct a new mental model. Chantraine, Joanette & Cardebat (1998: 272) fittingly refer to "right-hemisphere-damaged *nonaphasic* individuals". Right-hemisphere lesions, though not the cause of *aphasia proper*, can lead to discourse impairments; "verbal communication among right-hemisphere-damaged patients is usually *normal with regard to properly linguistic aspects*" (my emphasis throughout). It therefore seems that it would be both clinically and theoretically more efficacious and less confusing to call each deficit by a different name rather than positing one set of symptoms that are indicative of aphasia proper and another set that relate to aphasia in the broad sense (or pseudo-aphasia?). Both dysphasia and dyshyponoia are indicative of deficits in

3. 'Verbal' refers to communication expressed in words, though not necessarily orally (i.e., sign languages are also included).

verbal communication, but each refers to a specific isolable component, with its respective neurofunctional and therapeutic implications.

Joanette & Ansaldo (1999) thus propose to use the term 'language' to refer to all verbal communication (i.e., language system + pragmatics); Kasher (1991), on the other hand, proposes to call this overarching entity 'pragmatics'. But since there are undeniably two components of verbal communication, each of a different nature and bearing on different objects, Joanette and colleagues (e.g., Chantraine, Joanette & Cardebat 1998) are led to speak of language 'proper' and language 'in the broad sense', whereas Kasher is obliged to speak of linguistic pragmatics ('related to the left hemisphere') and nonlinguistic pragmatic competences (related to the right hemisphere). I see no advantage in calling two entities that behave "in an utterly different way" (Kasher 1991: 382) by the same name. I find it more natural and simpler to divide verbal communication into its linguistic[4] components (dealing with language as implicit linguistic competence) and its pragmatic components (dealing with implicit probabilistic inference), with linguistic pragmatics being a part of general pragmatics (i.e., all kinds of probabilistic inference). Whether there is a linguistic pragmatics independent of the rest of pragmatic competence is an empirical question. Linguistic pragmatic competence and nonlinguistic pragmatic competence are both pragmatic in nature, that is, probabilistically inferential. The language system, on the other hand, is different, namely nonprobabilistic and describable as a set of obligatory rules[5] (whatever the neuropsychological nature of its implicit computational procedures may be).

4. For the purpose of clarity, 'linguistic' will be used to refer to what pertains to the language system (i.e., phonology, morphology, syntax and semantics) and contrasted with 'pragmatic' which refers to the effect of any context on the interpretation of utterances. Implicit linguistic competence and explicit metalinguistic knowledge are neurofunctionally independent (Paradis 1994). There is probably also implicit pragmatic competence and explicit metapragmatic knowledge, even if this has not yet been neuropsychologically established in detail. In this context, 'implicit' means: not within the domain of conscious awareness, acquired incidentally and used automatically.

5. The rules of grammar described by linguists (generativists as well as writers of pedagogical grammars) are considered *obligatory* in the sense that if they are violated, the sentence is ungrammatical. For example, an adjective in French MUST agree with the noun it modifies in gender and number. Whether one's theoretical framework contains grammar rules or constructions, they are obligatory in that a sentence that violates a rule is ungrammatical and if it is not licensed by a given construction, it is likewise not a grammatical sentence; any violation of grammatical constraints results in an ungrammatical sentence. On the other hand, pragmatic inferences are not obligatory in that they admit of degrees of appropriateness. Short of logical inferences, which are necessary, all inferences are contingent and are only possible, plausible, probable, or very likely, given a set of circumstances. There may always be unperceived circumstances that could modify the correctness of a pragmatic inference.

Expanding the term "language" to include pragmatics and the term 'aphasia' to incorporate 'nonaphasic' symptoms introduces unnecessary ambiguities and requires one to constantly specify which aspect of language one is referring to. The protracted debate over whether there is greater right hemisphere participation in bilinguals than in unilinguals from the late 1970's to the mid-1990's is one illustration of what happens when one makes specific theoretical claims about "language" without specifying which of its possible meanings is intended (Paradis 1990, 1995). That is why I propose to replace 'language' with more transparent expressions or to use it only with appropriate specifiers. In this view, language (qua linguistic competence, as technically defined) is a component of verbal communication. So is pragmatics (inferences from contexts). The two are not "opposed" (Joanette & Ansaldo 1999: 530) but complementary (albeit isolable both clinically and for theoretical purposes).

It has been consistently reported in the clinical literature that verbal communication deficits subsequent to right-hemisphere brain damage are very different from those presented by individuals with aphasia (cf. from Hannequin, Goulet & Joanette 1987 to Champagne 1999); one routinely speaks of 'non aphasic language disorders' (McDonald 1993) when referring to right-hemisphere verbal communication impairments. The dichotomy will not go away simply because one gives both sets of divergent phenomena the same name, be it *language* or *pragmatics*. Nor should it be forgotten that, for the past 150 years, clinicians have traditionally referred to deficits affecting linguistic phenomena (phonology, morphosyntax and semantics) as *aphasia*, while, for at least the past 40 years, problems with the appropriateness relations between utterances and contexts, including discourse phenomena and nonliteral meanings, have been dubbed non-aphasic. Nothing is gained by giving two contrasting entities the same name.

9. Conclusion

The consensus is that whereas left-hemisphere-damaged individuals communicate better than they speak (Holland 1977), right-hemisphere-damaged individuals speak better than they communicate (Pakzard & Nespoulous 1997). One thing at least seems clear: there is a division of labour between the left and right hemispheres in subserving verbal communication. The nature and extent of each hemisphere's contribution remains to be explored in detail, as do the nature and chronology of the interaction between the two hemispheres in the course of deriving the meaning of an utterance. I agree with Bara, Tirassa & Zettin (1997) that communication and language can and must be kept independent of each other for research purposes and I would go one step further in stipulating that *verbal* communication and language (qua grammatical system) are separate, the latter being a necessary but not sufficient component of the former.

As mentioned above, details of which component or aspect of a component is subserved by which hemisphere have yet to be specified. The contribution of the frontal lobes will also have to be investigated, including whether the right and left frontal lobes make qualitatively different contributions (Alexander et al. 1989). It is still unclear whether (a) all nonliteral meanings are equally susceptible to damage, (b) the various types of nonliteral interpretation form a hierarchy of vulnerability, (c) different patients show preferential deterioration of different types of nonliteral meanings, thus pointing to the neurofunctional independence (or modularity) of these various aspects, and (d) the patient's ability to make appropriate inferences varies as a function of the clues from which something must be inferred (e.g., general knowledge, situation, discourse) or as a function of the nature of what is to be inferred (e.g., speaker's intentions or facts).

Individuals with right-hemisphere damage do not necessarily exhibit all of the symptoms that have been reported, just as not all individuals with left-hemisphere damage exhibit aphasic symptoms — only those with lesions in specific areas do. It is likely that dyshyponoiacs do not represent a homogeneous group, any more than aphasics do. As there are different types of aphasia (i.e., different types of impairment of various components of the grammar), there are likely to be different types of dyshyponoia, affecting different components of pragmatics or types of inference. But when individuals with right-hemisphere damage do exhibit communication impairments, their deficits are of a particular kind. They are qualitatively different from those of individuals with aphasia, and in fact, complementary. Also, like individuals with aphasia, right-hemisphere-damaged subjects have different patterns of deficits (Chantraine, Joanette & Ska 1998).

Like agrammatic patients (Hirst, Le Doux & Stein 1984), children, genetic dysphasics and second language learners are able to determine a speaker's intentions without going through the syntactic decoding process. To do this, among available compensatory mechanisms, they use right-hemisphere-based capacities, in particular, inference from context and general knowledge.

Verbal communicative competence comprises linguistic competence *and* pragmatic competence. Semantic meaning is underspecified; pragmatic meaning fits the situation. These two components are neurofunctionally distinct, and, to a considerable extent, anatomically dissociated. In the process of speaking, pragmatic ability determines the selection of available linguistic competence implicit procedures that are used to convey the message. Therefore, some pragmatic decisions must precede linguistic encoding (the speaker must decide on direct or indirect expression, on transparent or opaque expression if indirect, and on focus — selection of active, passive, or cleft construction).

The component of verbal communication subserved by the classical language areas (the perisylvian area) yields a semantic meaning that is *obligatorily* derived from the meanings of words and the structure of sentences. The verbal communication component subserved by areas of the right hemisphere yields a specific illocutionary or referential meaning that is *probabilistically* derived from the various contexts associated with the utterance.

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Cognitive grammar

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1. Introduction

Cognitive grammar is a comprehensive and unified theory of linguistic structure. Its formulation was initiated in 1976, and a general description was first presented in Langacker (1982). Though refined and greatly elaborated, the basic organization and central notions of the theory have survived its application to diverse languages and progressively wider arrays of challenging data. Among the many topics on which book-length studies have now been completed are locatives in French (Vandeloise 1986) and Cora (Casad 1982); transitivity in English (Rice 1987); Samoan clause structure (Cook 1988); case semantics in German (Smith 1987) and Slavic (Janda 1993); modern Aramaic morphology (Rubba 1993); middle voice in Spanish (Maldonado 1999) and modern Greek (Manney 2000); and English pronominal anaphora (van Hoek 1997). Extensive discussion and exemplification of the framework are available in Langacker (1990, 1999, 2009) and Rudzka-Ostyn (1988), while Langacker (1987a, 1991, 2008) provide a detailed, systematic exposition.

At its inception, cognitive grammar constituted a radical alternative to generative theory, whose subsequent evolution has however rendered the contrast less stark in many respects. The specific framework described here represents just one approach within the broad movement called 'cognitive linguistics', which in turn is part of the broader movement of 'functional linguistics'. Although the numerous research programs comprising cognitive and functional linguistics are synergistic and loosely compatible, particular approaches differ even on certain basic issues. As a case in point, the central claim of cognitive grammar — that grammar is *fully reducible to assemblies of symbolic structures* — would not be accepted by all cognitive linguists, let alone all functionalists. It goes considerably beyond the near-consensus view that grammar is strongly shaped by semantic and functional considerations (which is not *per se* necessarily incompatible with the generative claim of grammatical autonomy).

A cognitive approach to language can also be a pragmatic approach, for cognition figures crucially in linguistic behavior, social interaction, and contextual understanding. Despite its emphasis on conceptualization (broadly understood as encompassing all mental experience), cognitive grammar explicitly denies the existence of any sharp or specific boundary between pragmatic and linguistic considerations. It is in fact a pragmatically grounded theory of language in regard to its organization, its view of semantics, and even its account of grammar.

2. Organization

Language serves the basic *semiological function* of allowing conceptualizations to be symbolized by phonological sequences for purposes of thought and speech. The organization cognitive grammar ascribes to a linguistic system directly reflects this function. To permit the phonological symbolization of meanings, a language must at least comprise *semantic structures*, *phonological structures*, and *symbolic links* between the two. A fundamental claim of cognitive grammar is that *only* these are necessary. It is claimed, in particular, that lexicon, morphology, syntax, and even discourse patterns form a continuum (rather than discrete components) whose full description resides in assemblies of *symbolic structures* (i.e. symbolic linkages between semantic and phonological structures). In this way the theory achieves a substantial *conceptual unification*.

Cognitive grammar is highly *restrictive* due to the *content requirement*: the only elements ascribable to a linguistic system are (i) semantic, phonological, and symbolic structures directly apprehended as (parts of) overtly occurring expressions; (ii) schematizations of permitted structures; and (iii) categorizing relationships between permitted structures. Beyond the primary data of actual expressions, a language is therefore limited to structures derivable from such data by the fundamental cognitive abilities of *abstraction* (schematization) and *categorization*. The generalizations a speaker extracts can only reside in *schemas*, i.e. structures directly analogous to the data from which they are abstracted, but characterized in lesser specificity and detail. Thereby precluded are formal devices having neither semantic nor phonological content (e.g. arbitrary diacritics; phonologically zero syntactic 'dummies'; uninterpreted syntactic trees), as well as the derivation of surface forms from underlying structures. Relationships of categorization hold between schemas and the structures from which they are initially abstracted, or those which they are subsequently used to construct or evaluate.

Language use (and the basis for language acquisition) consists of *usage events*, in which full, contextually grounded understandings are paired with phonological occurrences in all their phonetic detail. To the extent that usage events are similar, schematization comes about through the reinforcing and progressive entrenchment of recurring commonalities, as well as the 'cancellation' (non-reinforcement) of features that do not recur. This abstraction can be carried to any degree, as more usage events are taken into account and the discernible commonalities become more tenuous. While semantically this usually involves substantial decontextualization, any facet of the context that consistently recurs across a set of usage events can be retained as a specification of the schema that emerges from them. It is therefore normal for conventional linguistic units to incorporate, as intrinsic aspects of their value, specifications that are often considered 'pragmatic' (e.g. features of the interactional or discourse context). From the standpoint of cognitive grammar, the situation where all such features are effectively eliminated by the process of cancellation represents a special, limiting case.

To the extent that semantic, phonological, and symbolic structures are cognitively entrenched and conventionally established within a speech community, they constitute part of a given speaker's apprehension of the linguistic system. Abstracted from usage events, these conventionalized units are invoked for the categorization of subsequent events. These are judged *conventional* ('well-formed') provided that they merely *elaborate* (or *instantiate*) the schematic specifications of the categorizing units, whereas any conflict in specifications represents an *extension* vis-à-vis established convention, extreme cases being perceived as violations. The set of categorizing relationships by which an event is assessed constitute its *structural description* as an expression of the language. As expressions recur and coalesce to form established units, by definition both they and the categorizing relationships involving them become part of the linguistic system. This has the consequence that a linguistic category is typically *complex*: it is best characterized as a *network* of semantic, phonological, or symbolic structures, usually centered on a *prototype*, connected by relationships of elaboration and extension. Generally, for instance, the alternate senses of a lexical item form a complex category (*polysemy*).

A brief example will illustrate some standard notations. In its prototypical value, the morpheme *cat* can be represented as follows: [CAT/cat]. Capital letters abbreviate a semantic structure, and small letters a phonological structure, while a slash represents the symbolic relation between them. Square brackets (or boxes) enclose a structure with the status of an established conventional unit, whereas parentheses (or closed curves) enclose novel structures. The morpheme *cat* is polysemous: another established sense applies specifically to an adult feline (in opposition to *kitten*). These two lexical variants thus participate in the categorizing relationship [CAT/cat] → [ADULT CAT/cat], the solid arrow indicating elaboration. *Cat* is also applied to large felines, such as lions, as reflected in the categorizing relationship [CAT/cat] –––> [LION/cat], where the dashed arrow indicates extension from a more prototypical value.

The symbolic units of a language vary in their degree of semantic and phonological specificity as well as their *symbolic complexity*, i.e. their decomposability into smaller *symbolic* units. The symbolic units traditionally considered *lexical items* are phonologically specific, usually fairly specific semantically, idiosyncratic in some respect, and of limited symbolic complexity (a *morpheme* being symbolically non-complex). Cognitive grammar, however, treats any fixed expression as a lexical item, regardless of its size, symbolic complexity, or regularity with respect to grammatical patterns. Subsumed under lexicon, therefore, are vast numbers of standard collocations, usual ways of phrasing things (the basis for 'idiomatic' speech), and formulaic expressions of any length (e.g. proverbs). Symbolic units tend to be considered *grammatical* (as opposed to lexical) to the extent that they are semantically and phonologically schematic, but cognitive grammar views this parameter as being continuous rather than dichotomous. Grammatical *markers* are phonologically specific but semantically quite schematic (yet still seen as meaningful). Basic grammatical *classes* (e.g. noun and verb) are claimed to have universally applicable characterizations that are highly schematic both semantically and phonologically. Grammatical *patterns* (or *rules*) take the form of *constructional schemas*, i.e. semantically and phonologically schematic structures that are *symbolically complex*. Abstracted from specific complex expressions, such schemas capture any commonality in their formation and function as templates for the assembly of novel expressions on the same pattern.

3. Conceptualist semantics

Meaning resides in *conceptualization*, in the broadest sense of that term. It subsumes both fixed and novel conceptions; sensory and motor experience; both instantaneous conceptions and those unfolding over a significant span of time; and full apprehension of the physical, social, cultural, and linguistic context. As the basis for its meaning, every expression and every symbolic unit invokes some body of conceptual *content*, and on that content it imposes a particular *construal*. The two are of equal importance to linguistic meaning — elements that invoke the same content can nonetheless contrast semantically because they construe it in different fashions.

The content supporting an element's semantic characterization can be limited or of indefinite expanse, and ranges from being richly detailed to being so schematic that it is almost vacuous. This content comprises a set of *cognitive domains*, each pertaining to a different facet of the element's semantic value. Any kind of conceptualization is capable of being invoked in this capacity, from the basic experience of time, space, color, taste, etc., through concepts of progressively greater complexity, to knowledge systems of essentially unlimited scope. As facets of its characterization, for example, the chess term *rook* evokes the basic domain of space (to specify its shape, as well as the board's layout), the simple concept of a straight line (pertaining to its movement), numerous more elaborate concepts (e.g. the notion of capturing), and a large body of knowledge regarding the rules, objectives, and strategies of the game.

While certain domains and certain specifications are more central and important than others for an element's characterization, there is in principle no fixed or definite boundary between our overall knowledge of an entity and the meaning of an expression designating it — cognitive grammar adopts an *encyclopaedic* view of linguistic semantics (Haiman 1980). Rather than treating expressions as metaphorical 'containers' necessarily holding only a limited quantity of the metaphorical substance called 'meaning', it sees them as providing an active, engaged conceptualizer with access to an open-ended body of knowledge evoked in a flexible, context-dependent way (Reddy 1979). It follows that a particular expression may assume a slightly different value on every occasion of its use. To reinforce this conclusion, note that a speaker's apprehension of the preceding discourse and of the immediate interactive context qualify as conceptualizations, hence as cognitive domains, and can thus be counted as part of an expression's meaning. Such specifications may be specific or schematized, and may be central to an element's semantic value or highly peripheral, but in some way and to some degree they are always present.

Every expression and every symbolic unit imposes a particular *construal* on the content it invokes. A speaker who wishes to describe a certain conceived situation must, for example, make decisions concerning its *scope* — which aspects of the situation are to be included in the expression's intended coverage — as well as the level of specificity at which they are to be characterized. The speaker must also adopt some *perspective* on the situation. One component of perspective is the *vantage point* assumed, be it spatial or more abstract. Another component is how *objectively* or *subjectively* a given entity is construed, i.e. whether it is put 'onstage' as a specific *object* of conception, or whether it remains 'offstage' and implicit as either the *subject* of conception or part of the conceiving circumstances. For instance, the adverbial expression *before now* mentions the time of the speech event explicitly and thus construes it objectively, whereas a past-tense morpheme construes it subjectively (as an implicit reference point). Another component of perspective is the *direction of mental scanning*, illustrated by the semantic contrast between *The roof slopes steeply upward* and *The roof slopes steeply downward*.

Objective construal is one of several kinds of *prominence* that have to be recognized and distinguished for analytical purposes. Another kind of prominence is *profiling*, or *reference within a conceptualization*. Within the conceptual *base* comprising the body of content it invokes, an expression always selects some substructure as the one it *designates* (refers to). The term *rook*, for example, invokes the conception of a chessboard with numerous pieces, but within that scene it *profiles* a particular piece. Likewise, the term *knee* evokes as its base the conception of a leg, within which it profiles the major joint. Many expressions are analyzed as profiling *relationships*. Thus *before* profiles a relationship of temporal antecedence between two schematically conceived events. *Arrive* evokes as its base the conception of an entire journey in which some destination is reached, and within that base it profiles the event of finally reaching it. Expressions that profile relationships manifest another kind of prominence in how they portray their participants. One participant, termed the *trajector*, is generally singled out as the *primary figure* within the profiled relation (in the case of *arrive*, for instance, the trajector is the mover). If a second participant is also singled out for focal prominence, it is called the *landmark* (analyzed as the *secondary figure*). Observe that *before* and *after* evoke the same conceptual content and profile the same relationship (there is no *referential* distinction between them). Their semantic contrast resides in whether the later event is focused as a landmark for purposes of temporally locating the earlier event (the trajector), or conversely.

4. Grammar as symbolization

An expression's grammatical class is determined by the nature of its profile. A basic distinction is drawn between expressions that profile *things* and those that profile *relationships* (under abstract definitions of those terms; see Langacker 1987b). Relationships divide into *atemporal* relations and *processes*, which are *temporal* in the specific sense that their evolution through time is highly salient. Standard abbreviatory notations are given in Figure 1. Nouns are characterized schematically as expressions that profile *things*, as are pronouns, determiners, and higher-order nominal expressions such as full noun phrases. Adjectives, adverbs, and prepositions are among the classes that profile various sorts of *atemporal relations*. A verb profiles a *process*, as does a modal, a tense-marker, or a full finite clause.

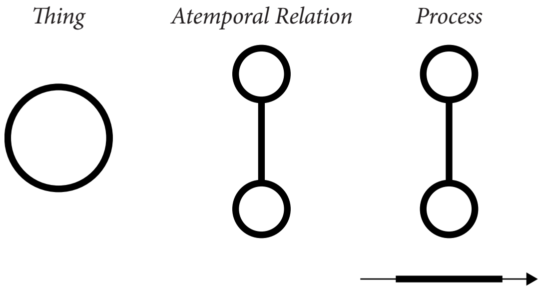

Figure 1.

Grammar resides in patterns — represented by *constructional schemas* — for constructing *symbolically complex expressions*. A typical *construction* consists of two *component* symbolic structures that are *integrated*, both semantically and phonologically, to form a *composite* symbolic structure. Integration depends on *correspondences* between subparts of the two components; corresponding entities are superimposed (their specifications merged) to form the composite structure. Consider, for example, the prepositional object construction (e.g. *near me*; *beside a lake*; *under that tree*), whose semantic integration is diagrammed in Figure 2. (Not depicted is its phonological integration, wherein the structure representing the noun phrase object is equated with the one that directly follows the preposition in the temporal sequence.)

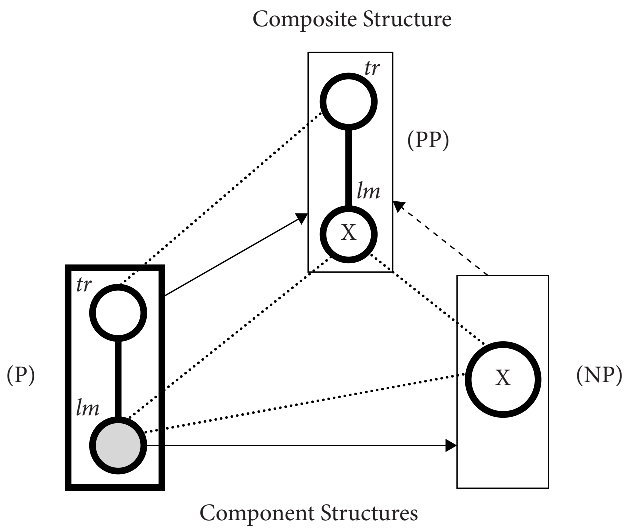

Figure 2.

Semantically, the preposition profiles an atemporal relation between a trajector (*tr*) and a landmark (*lm*), each characterized schematically (in this case just as *things*). A noun phrase profiles an *instance* of a particular thing *type* (an instance that is *grounded* in the sense of having some identificational status vis-à-vis the speech event participants); here, the various semantic specifications of the noun phrase are merely abbreviated as *X*. A dotted correspondence line indicates that the landmark of the preposition is identified with the profile (conceptual referent) of the nominal component. The composite semantic structure, obtained by superimposing and merging the specifications of the corresponding entities, preserves the relational profile of the preposition and thus designates an atemporal relation between a schematic trajector and a specified landmark. Additional dotted lines register the resulting correspondences between elements of the composite conception and the two components.

Traditional grammatical notions can be defined in terms of such symbolic assemblies. For example, the component structure whose profile is inherited at the composite structure level (the preposition in Figure 2) is called the *profile determinant* and enclosed by a heavy-line box; the profile determinant at a given level of organization is most reasonably characterized as a *head*. It is usual for one component structure to elaborate a schematic substructure of the other. In this example, the preposition's landmark is an *elaboration site* (marked by shading) which the nominal object instantiates (as indicated by the solid arrow connecting them). The object is thus a *complement*, definable as a component structure that *elaborates* a salient substructure of the head. A *modifier* is a component structure a salient substructure of which is *elaborated by* the head.

In conjunction with their phonological symbolizations, the structures in Figure 2 comprise an *assembly* of symbolic structures linked by relationships of correspondence and categorization. Within this assembly, the composite structure has special status by virtue of being the *target of categorization* by the two components: it generally constitutes an *elaboration* with respect to the head (→), and an *extension* with respect to the other component (‒‒‒>) owing to a difference in profiling. Its foregrounded status as the target of categorization makes the composite structure available for comparison to the conceived situation being coded linguistically, or to function as a component structure in a higher-order symbolic assembly. When composite structures are thus successively invoked as components in higher-level constructions, the result is what is traditionally recognized as grammatical *constituency*.

Importantly, component structures are not conceived as 'building blocks' out of which the composite structure is 'constructed'. Though unavoidable, that metaphor is inappropriate in many respects. Component structures merely *categorize* and *motivate* the composite structure, which may incorporate conceptual or phonological material not contributed by either component, and generally diverges from the predictable outcome of compositional patterns: it is either more specific (an *elaboration*) or constitutes an *extension* (generally metaphorical or metonymic). Thus, while cognitive grammar does recognize patterns of semantic composition (the semantic side of constructional schemas, as in Figure 2), it claims that linguistic semantics is characterized by *partial* (rather than *full*) *compositionality*.

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Cognitive science

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1. Definition

Cognitive science, the interdisciplinary study of cognitive phenomena, has its origins in philosophy and can be viewed as the empirical pursuit of age-old questions in the philosophy of mind. Perhaps the word that best captures the field of cognitive science is *diversity*. Cognitive scientists study a broad range of cognitive phenomena, including attention, perception, memory, language, learning, and reasoning. Moreover, researchers in cognitive science come from a wide range of backgrounds. The field draws from a number of disciplines including philosophy, linguistics, psychology, computer science, anthropology, sociology, and the neurosciences. The upshot of the varied nature of the enterprise is that convergent findings often arise out of a number of complementary research methods.

Unifying the diversity in cognitive scientists' topics, backgrounds, and methods is a set of core questions and a shared approach that uses notions of computation and information processing as motivating metaphors and as explanatory concepts. All cognitive scientists are committed to the belief that the human mind can be productively viewed as a complex system involved in the acquisition, storage, transformation, and transmission of information. Though cognitive scientists differ in their interest in the biological substrate of intelligent behavior, most are committed to the thesis that the explanation of cognitive phenomena involves an account of formal structures and processes, their representational significance, and their physical implementation. The principal characteristics of the field, then, include commitment to some species of mental representation and the tendency to employ formal systems, especially computational models, in their descriptions of cognitive phenomena.

The overarching goal of cognitive science is to develop models of cognitive processes that link the disparate levels of analysis tackled by the field's eclectic set of researchers. It is no easy feat to link events noted by cognitive neuroscientists to events reported by cognitive anthropologists. Indeed, there is a daunting explanatory chasm between our conception of the brain and our conception of the mind. However, describing cognitive phenomena in terms of formal systems helps to bridge these epistemological gaps. Although the questions of which formal system is most adequate, and, indeed, whether *any* formal system is completely adequate, are hotly contested, the tendency towards the use of formal models persists.

What follows is (i) a brief history of cognitive science broken down by its contributing fields; (ii) an account of the multifarious methods of cognitive science; (iii) a discussion of some of the main issues in the field to date; and, finally, (iv) a short section on the relationship between pragmatics and cognitive science.

2. History of contributing fields

2.1 Philosophy

Cognitive science involves an empirical approach to questions that have long been considered by philosophers. Perhaps the most notable is the mind–body problem concerning the relationship between mental characteristics of mind and physical characteristics of the brain. Whereas the philosophical problem involves consideration of whether and why such disparate phenomena might (or might not) be connected, the problem in cognitive science is to characterize the relationship between mind and body for any given phenomenon.

The majority of cognitive scientists have adopted, at least implicitly, one of two positions on the mind–body problem. The first is materialism, and is favored especially by people working in neuroscience. Materialism involves the belief that the only adequate characterization of mental states is in terms of their reduction to physical states of the brain. The second position is functionalism, and is popular among cognitive scientists pursuing questions in psychology and artificial intelligence. Functionalism, although compatible with materialism, differs from the latter in the belief that the essential characteristics of mental states are their informational properties, rather than their physical characteristics.

Whereas the materialist characterizes cognitive phenomena in terms of the physical phenomena with which they are seemingly identical, the functionalist characterizes cognitive phenomena in terms of their function in the cognitive system. Thus for the functionalist, the chief characteristics of cognitive phenomena are not the physical characteristics of the systems in which they occur, but their role in the information processing system. This includes the relationship between inputs to the cognitive system, the relationship between different mental states, and the consequent output of the system.

Other philosophical issues tackled by cognitive scientists include the question of intentionality (how it is that words, actions, and mental representations in general can have content); the issue of whether human knowledge should be characterized as innate or learned; rationalism versus empiricism (the relative importance of the mind as opposed to the external environment in determining our conception of reality); and epistemology (what it is to know something; in cognitive science, this debate has centered on the possibility of building intelligent computers).

As noted, cognitive science has branched off from its philosophical roots, abandoning the thought experiment for the empirical methods of the natural and social sciences. To some extent, one can conceptualize artificial intelligence (AI) as an extension of philosophy, where the philosophers' logical tools have been automated. Nonetheless, philosophy continues to have a strong influence on cognitive science in forcing clarity of concepts and the explanatory adequacy of its theories.

2.2 Artificial intelligence

Perhaps more than anything else, cognitive scientists have been inspired by the invention of the computer and its attendant theoretical constructs, such as information theory and symbol processing. The movement in the 1950s in computer science towards construing computers as symbol processors rather than mere number crunchers led some of AI's founders to a new way of thinking about the mind. In fact, the role of the computer in cognitive science is two-fold. First, it serves as an inspiring metaphor for mind. Second, it serves as a tool for building formal models of intelligent behavior.

The beginnings of the field of artificial intelligence is generally put at 1956, the date of an academic conference at Dartmouth College in which the topic was the production of computer programs capable of intelligent behavior. From the very inception of the field then, artificial intelligence researchers were committed to the tenet that intelligent behavior could be characterized in a formal manner and simulated on computers. However, the attempt to build formal models of the brain dates back even earlier. McCulloch & Pitts (1943) proposed a mathematical model of neural mechanisms with an eye toward exploiting their models in the explication of cognitive phenomena. Their work, although long ignored, was paradigmatic of cognitive science efforts, first, in its interdisciplinary character resulting from the collaboration between a mathematician (Pitts) and a neuroscientist (McCulloch); and, second, its attempt to provide a formal mechanism for theorizing about cognitive phenomena.

2.3 Psychology

The field of cognitive psychology began mainly as a reaction against behaviorism, the reigning theory of psychology in the 1950s. Profoundly committed to controlled experimentation and the study of observable phenomena, behaviorists considered mental phenomena such as thoughts, images, and ideas to be vague categories whose ontological status was questionable. Because mental phenomena were not directly observable, they were deemed unfit for scientific investigation. However, the development of the computer and concomitant theoretical developments in information theory (Shannon 1949) offered psychologists a new way of discussing mental phenomena.

The computer served as an example of a mechanism whose observable, intelligent behavior did not require an appeal to introspective knowledge. Moreover, the behavior of the computer could ultimately be attributed to physical processes. The construal of the human mind as an analogue of the computer thus had a legitimating effect on the status of mental phenomena as potential objects for scientific study. Further, it provided cognitive psychologists with a language for discussing unobservable mental phenomena in a rigorous way.

The human mind is thought of as implementing a formal system. The cognitive scientist's job, then, is to outline the symbolic representations and transformation of those representations that intervene between the environmental input to a person and his/her behavioral output. The mind-as-computer analogy has also been used to develop a vocabulary for discussing cognitive mechanisms based on that used to discuss mechanisms in the computer. For example, programs, compilers, and buffers are often invoked as analogues of human mental processes. Armed with the theoretical machinery of computer science, cognitive scientists have studied human decision making, syllogistic reasoning, reasoning under uncertainty, memory organization, problem solving, auditory and visual perception, planning, learning, development, and aging.

Work in cognitive psychology, besides being driven by the metaphor of the mind as an information processor is paradigmatic of cognitive science in its employment of formal models of cognitive phenomena. For example, studies of decision making were influenced by and had an impact on formal theories of intelligent decision making. Newell & Simon's early work (1965) on human problem solving was influenced by search theory, automated problem solving, and formal theories of knowledge representation.

An important component of cognitive psychology is the way individuals' cognitive abilities change over the course of development. Besides attempting to characterize the mechanisms that underlie adult cognitive abilities, cognitive psychologists also describe the changes that those abilities undergo from birth to death. This includes the many changes that occur in the child's cognitive abilities as a result of maturation, differences due to experience (such as those between novices and experts in a given domain), as well as differences due to aging, as in the decline in memory in the elderly population.

Moreover, one of the biggest areas in developmental psychology concerns the question of language acquisition. Though this research has chiefly focused on the growth of children's syntactic knowledge, the acquisition of pragmatic aspects of language ability has also been addressed. Bates (1976) suggests that children's competence with speech acts precedes their acquisition of other aspects of language. Moreover, the child's early communicative knowledge helps pave the way for subsequent language development. Overall, such research demonstrates the centrality of communicative intention, utterance function, interactive context, and, perhaps most importantly, the adult's interpretive resources for the process of language acquisition.

A related question concerns the relationship between language acquisition and conceptual development. Language acquisition begins in the child's second year. However, traditional Piagetian accounts of development suggest that the two-year-old, although she or he has an extensive set of perceptual and motor procedures for obtaining information about the world, lacks the capacity for truly symbolic concepts. In contrast to the Piagetian dogma, Mandler (1992) suggests that, in fact, children's conceptual ability develops quite early, in the form of *image-schemas*. Image-schemas are mappings from spatial structure, abstract aspects of trajectories of objects and their interactions in space, onto conceptual structure. Mandler (2004) argues that the perceptual sophistication of very young children is sufficient to support image-schema representation; moreover, she points to the implication of image-schemas in cognitive linguistics (Johnson 1987; Lakoff 1987; Langacker 1987) and suggests that the initial stages of language acquisition involve mappings between words and image-schemas.

Another trend in developmental research involves collaboration with cognitive anthropologists to explore the close relationship between the acquisition of language and the acquisition of cultural competence. Ochs & Schieffelin (1976), for instance, argue that cultural competence is both the raw material and the end-product of language acquisition. Researchers have begun to realize that culture is an important variable that affects the manner in which both language and cultural competence are acquired (Harkness 1992). Consequently, the field has witnessed increasing convergence on questions of the acquisition of culture and more general developmental issues (Sinha, 2000).

2.4 Linguistics

Another key component in the rise of cognitive science was the development of generative grammar by Noam Chomsky (1957, 1965). Chomsky's approach to language was paradigmatic of cognitive science in its use of concepts from automata theory in computer science and in approaching natural language as a string of symbols that could be described as a formal system. Chomsky's review of B.F. Skinner's *Verbal Behavior* is legendary for the way in which it largely silenced behaviorist approaches to language.

Although the initial Chomskyan paradigm, in which natural language syntax is approached in a purely formal way, played a crucial role in the early development of cognitive science, subsequent movements have focused more on the connection between form and meaning. Developments over the past 30 years in cognitive semantics have led to a research program whose results are directly applicable to cognitive science. Under this conception the function of language is to set up construals, to map between domains, and to set up mental spaces with properties such as accessing, spreading, and viewpoint. (See Fauconnier 1985 or Fauconnier 1997 for a comprehensive treatment of these issues.)

Under this construal of language, natural languages provide us with a means to trigger the complex projection of structure across discourse domains. Work in this vein has included investigations revealing the important role that metaphoric and metonymic mappings play in lexical semantics. This includes work done by Reddy (1979), Lakoff & Johnson (1980), Radden (1996), Kovecses (1996), Sweetser (1990), and Talmy (2000), among others. The extraction of abstract schemas in semantic construction has also proven to be extremely useful in the analysis of analogical thought.

2.5 Neuroscience

Cognitive neuroscience concerns the identification of the biological structures and events involved in the acquisition of information from the environment (sensation), its interpretation (perception), its storage (memory) and modification (learning). Other issues address how we use information to predict the consequences of our actions (decision making), to guide our behavior (motor control), and to communicate (language) (see Albright & Neville 2003 for review). Early work in this area focused on the issue of localization of function, as neurologists and neuropsychologists correlated the areas of their patients' brains damaged by stroke or tumor with their resultant cognitive deficits. Perhaps the most famous example is provided by Paul Broca, who argued that the left frontal lobe is responsible for speech production. Other work in neuroscience has concerned the electrochemical basis of neural function that has helped elucidate the mechanisms that underlie learning and memory formation.

While most early work in cognitive science proceeded independently of neuroscience research, the widespread availability of non-invasive brain imaging technologies has led to an increasingly synergetic relationship between psychology, linguistics, and neuroscience. A great deal of neuroimaging research is aimed at brain mapping, or describing the brain regions involved in various sorts of cognitive processing, including perceptual, memory, and language tasks. Moreover, cognitive scientists have used neuroimaging data to address long-standing debates about the representational basis of mental imagery (Kosslyn, et al. 2003), the locus of attentional selection (Kanwisher 2000), and the organization of semantic memory (Chao & Martin 2001). Neuroimaging studies of language function have confirmed the role of classically defined language regions such as Broca's area and Wernicke's area, and point to the importance of other regions as well (Bookheimer 2002). Additionally, neuroscientists have begun to consider how the principles of neural function might be used to explain word meaning and syntactic organization (see e.g. Pulvermuller 2003).

2.6 Current directions

In early cognitive science, much emphasis was placed on mental representation and thought in a single individual. In recent years, however, greater emphasis has been placed on how representations are built, shared, and updated by multiple individuals during interaction. A key finding is that people naturally establish common ground — a mesh of knowledge from past experiences, their immediate surroundings, and shared culture, and that they rely on it to achieve understanding and complete joint tasks (Clark 1996). Some research on interaction focuses on how people align linguistic representations during conversation (e.g. Pickering & Garrod 2004). Other research focuses on the role of gesture during spoken interaction, including its utility in completing joint tasks (Clark & Krych 2004), narratives and story re-telling (McNeill 1992), and (c) explaining or remembering relatively abstract phenomena, such as math (Goldin-Meadow 2003).

This move towards the study of interaction is consistent with the field's growing appreciation of cognition as emerging from our interactions with the material, social, and cultural world. In neuroscience, this is marked by two research trends: first, the study of the interdependence of perceptual and motor mechanisms; and, second, the study of social cognitive neuroscience, aimed at identifying the neural mechanisms that subserve the perception of affective and socio-emotional cues. In artificial intelligence, this trend is marked by the growth of machine learning, the field of computer science that explores techniques in which a machine acquires knowledge from its previous experiences. In addition, the importance of the social world has been modeled computationally using the modeling paradigms of artificial life. In these models, whole populations of autonomous, interacting agents are simulated so that researchers can examine the conditions that lead to coordinated activity. In robotics, this philosophy is extended even further, as researchers examine how intelligent behavior can arise from the dynamic interaction between the robot's physical capabilities, its cognitive system, and its external physical and social environment (see Clark 2001).

Indeed, with the internet boom and the ubiquity of electronic devices such as laptops, cell phones, and personal digital assistants, cognitive science is even moving out of the ivory tower and into the work place. High-technology companies and many laboratories in academic settings have established research groups to study and evaluate how people interact with technology and how they work with each other using various media, such as the internet, video-conferencing systems, and instant-messaging systems. Cognitive scientists in this setting use many different methods to study human behavior in the work environment, ranging from discourse analysis to ethnography to eye-tracking (see Hollan, Hutchins & Kirsh 2000). In keeping with cognitive scientists' increasing interest in emotion, some of this work has focused on affect, and the emotional impact of technology on its users (Norman 2004; Picard 2000).

3. Methods

3.1 Methods for investigating behavior

3.1.1 *Psychological experiments*

A key contribution of psychology to cognitive science is the practice of conducting controlled experiments. Experiments test a particular hypothesis about the relationship between two or more variables: the variables the experimenter manipulates, termed the *independent variable*; and the variable measured to detect the effects of that manipulation, the *dependent variable*. Hypotheses in cognitive science usually concern how manipulating some facet of the input to the cognitive system changes its behavioral output. Conducting experiments allows the cognitive scientist to reject hypotheses that generate false predictions about how various manipulations affect cognitive performance.

Experimental studies of behavior can thus provide both the raw material for the cognitive scientist, in revealing behavioral effects that must be explained, and, a means to evaluate theories of cognitive processes. However, traditional experimental methods have been criticized for the tendency to overemphasize cognitive phenomena that are easily addressed by experiments and a corresponding under-emphasis on efforts to integrate experimental findings into unified theories of cognition (see especially Newell 1973).

Further, the more traditional methods of cognitive psychology have come under scrutiny for their lack of ecological validity. This critique consists of the charge that the cognitive phenomena addressed by experimental methods of psychology are not necessarily relevant or applicable to cognition in everyday situations (Cicourel, 1996). The laboratory is said to be an impoverished setting that fosters unnatural strategies. A closely related charge is that of 'decoupling' (Reitman 1970), the attempt to study the cognitive phenomenon in which one is interested in isolation of other factors. By its very nature, conducting experiments in a laboratory discounts the possibility that the context of cognition might be an important determinant of behavior.

3.1.2 *Naturalistic observation and ethnography*

One alternative to experimental techniques is the anthropologist's method of naturalistic observation and ethnography. This method involves the observation and recording of intelligent behavior in the setting in which it normally occurs (Hutchins 1995). For instance, the investigation of child language acquisition has included naturalistic study of children in the process of acquiring a language. Such an investigation requires the observer to be as non-intrusive as possible, or reflecting on the manner and extent of her influence on the phenomenon under investigation. A language acquisition study, for instance, might involve the audio- or videotaping of a child's interaction with his primary caregiver. The investigator's observations could then be coded systematically to track or correlate the growth of the child's vocabulary, knowledge of syntactic structure, and pragmatic language ability.

The virtue of naturalistic observation is that it yields an extremely rich data set. In some cases, the sheer mass of data will far outweigh the 'mass' of theoretical framework for incorporating that data. Moreover, while observation is ideal for providing descriptive generalizations of a class of phenomena, it is less good for providing persuasive arguments for the casual relationship between elements in a theoretical framework. Because the controlled setting of the laboratory affords unconfounding the many variables that contribute to intelligent behavior, it is often useful to supplement naturalistic observations with controlled experiments performed in a laboratory.

As befitting the interdisciplinary nature of cognitive science, perhaps the best resolution of the tension between the ambiguity of field studies and the impoverished setting of the laboratory is to promote cross-talk between the two approaches. This involves extensive use of naturalistic observation to define the nature and scope of a given phenomenon, followed by more carefully controlled experimentation in the laboratory. Additionally, there is the possibility of negotiating a compromise between the ecological validity of the naturalistic setting and the control of the white room by performing experiments in naturalistic settings themselves. While this approach precludes the experimenter from exerting complete control over the setting, participants are less likely to employ atypical strategies induced by the conditions in the laboratory. This helps insure that the investigator is observing cognitive processes that govern agents' normal behavior.

3.1.3 *Linguistic methodologies*

Traditional linguistic methods as well as the extension of those methods by researchers in cognitive semantics are a valuable tool for the cognitive scientist. Syntactic methodology is thought of as experiments that manipulate the form of sentences. The methods of cognitive semantics extend upon these methods in order to evaluate hypotheses about how background and contextual knowledge affect the meaning of a given utterance. Whereas the syntactic methodology relies upon judgments of grammaticality, cognitive semantics involves judgments of the plausibility of a range of inferences evoked by a given sentence/utterance. Further, these investigations often explore the impact of varying background assumptions and contextual circumstances.

Historical and comparative linguistics, that is, investigation of how a given language changes over time and how it compares to other languages, also provide useful information for cognitive science by revealing the impact of basic cognitive processes in conventionalized language use. For instance, words often take on new meanings via metaphorical extension, as when verbs of perception come to mean 'understanding' or 'knowledge' (Sweetser 1990). Tracking the development of words that grammaticize can provide insights into the more salient aspects of conceptualization, especially when parallel diachronic developments show up in unrelated languages or when they mirror patterns in conceptual development (Gibbs 1992). The Old English predecessor of *may* (*magan*) changed over time from a meaning that referred to one's physical ability to the more epistemic meaning of the modal *may* in modern English. This pattern of subjectification, in which word meaning changes from an objective characterization of reality to one that reflects the speaker's understanding or estimation of reality, is a major process in language change (Langacker 1990).

3.1.4 *Eye tracking*

A variety of techniques are available for measuring people's eye movements, and consequently eye-tracking studies have become increasingly popular in cognitive science. Eye movements during reading are typically used to index processing difficulty, where the assumption is that the longer a reader fixates a word, the more difficult that word was to process. Psycholinguists use eye-tracking during reading to test various hypotheses about the relative processing difficulty of different syntactic constructions and how supportive semantic and pragmatic context affects processing difficulty (Rayner & Liversedge 2004). While eye-movement registration techniques used to monitor reading are relatively constraining, recent years have witnessed the development of head-mounted eye-tracking systems that can be used to monitor eye movements during more natural communicative situations.

Eye movements during or preceding the production and comprehension of speech are thought to index visual attention and have been used to test hypotheses about the time course of these language processes. In the visual world paradigm, listeners sit in front of a display of real or pictured objects, and their eye movements are tracked as they carry out actions on those objects. In production studies, speakers typically fixate objects approximately 900 ms before referring to them (Griffin 2004). In comprehension studies, listeners shift their gaze to indicate how they understand the unfolding speech signal (Tanenhaus et al. 1995). This paradigm has been used to investigate the time course of processing linguistic phenomena such as anaphora, ambiguity, and thematic roles (Tanenhaus 2004). Cognitive scientists have also tracked eye movements during collaborative tasks to study interactive strategies, such as how speakers establish common ground (Keysar et al. 2000; Metzing & Brennan 2003).

Eye-tracking has also been used to study relatively complex behavior in naturalistic settings such as interacting with web browsers. In such studies eye movements can provide a marker of people's visual attention as well as revealing the strategies they use to solve complex, multi-step problems. In some cases, eye movements suggest the existence of low-level strategies not available to the subject's conscious awareness. For example, in driving, rapid task swapping is observed between multiple subtasks (Land 1992). In a natural hand eye task in which subjects had to reproduce a design made of blocks, eye-tracking measures suggested that rather than storing task-relevant information in working memory, people broke the task down into simpler sub-tasks that allowed them to postpone the gathering of task-relevant information until just before it was needed (Ballard, Hayhoe & Pelz 1995). These unconscious measures of people's behavior reveal a far greater reliance on information in the external environment than indicated by their self-reports. For review of eye tracking methods and findings, see Richardson & Spivey (2004).

3.2 Neuroscience techniques

3.2.1 *Neuropsychology and lesion studies*

One of the oldest techniques for investigating the brain bases of behavior is the lesion study. When the brain is damaged as a result of a stroke, an accident, a tumor, or other illness, we can observe the effect of that damage on cognitive functioning. For instance, it has long been known that damage to the frontal cortex impairs planning ability, and that damage to the left hemisphere impairs one's ability to use language. The general aim of neuropsychological research is to correlate the site of brain damage to the loss of a particular sort of cognitive ability. The way this research usually proceeds is to administer behavioral tests to a group of patients who have incurred similar sorts of brain lesions. For instance, a cognitive scientist interested in the role of the hippocampus in consolidating memories would compare the performance of patients with lesions in the hippocampus to normal controls on a number of memory tasks.

In any group of brain damaged patients there is bound to be substantial variability in the exact location of the lesion site, thus making it difficult to form generalizations that relate damaged structure to damaged function. This problem is somewhat attenuated by recent advances in brain imaging that allow neuropsychologists to record the lesion locations of a large number of patients onto a standard map of the brain. The particular lesion locations can then be correlated with patients' performance on various behavioral tests. Known as voxel-based lesion symptom mapping, this technique produces color-coded pictures of the brain that indicate the degree of correlation between injury to specific regions of the brain and any particular cognitive deficit (Bates, Wilson, Saygin, Dick, Sereno, Knight, & Dronkers 2003).

However, interpretation of lesion studies is not as straightforward as it might, at first, seem. Brain damaged patients vary in the extent to which their brain is able to reorganize and recover lost functions (a phenomenon known as plasticity). Plasticity also hinders the extent to which one can generalize over groups of patients, because the neuropsychologist never knows whether a particular patient's behavior is representative of some general facet of brain organization or of some idiosyncratic phenomenon pertaining only to that patient.

Perhaps most importantly, one cannot always conclude from a correlation between a behavioral deficit and a lesion site that there is a straightforward relationship between the two. The correlation between loss of function and lesion site (e.g. parsing ability with Broca's area) might be due to the fact that the impaired brain region is directly responsible for the cognitive ability — in this case parsing. However, another possibility is that the lesion site interrupts fibers of passage to and from areas that are actually responsible for the cognitive task in question. A further possibility is that the lesion site affects a biochemical system with a widespread influence.

3.2.2 *Brain imaging*

As noted above, brain imaging techniques have been developed to supplement neuropsychological techniques by providing evidence of the precise location of the lesion site. Whereas previously, the exact site of a patient's lesion could not be ascertained until an autopsy could be performed, noninvasive techniques such as computerized axial tomography (CAT), positron emission tomography (PET), and magnetic resonance imaging (MRI) provide the cognitive scientist with images of the patient's brain that can be interpreted with respect to that patient's performance on behavioral tests of cognitive function. Noninvasive imaging techniques can also complement neuropsychological techniques by providing us with images of healthy brains.

Whereas CAT and MRI yield static images of the brain, techniques such as PET and functional magnetic resonance imaging (fMRI) are used to measure dynamic changes in brain activity. In PET, for example, the patient is injected with a mildly radioactive substance and placed on a table that moves through a tube containing gamma ray detectors. When positrons emitted from the radioactive substance collide with electrons in the tissue, they give off gamma rays. PET detects those gamma rays and determines the precise location of the tissue from which they arose. PET can provide images of blood flow as well as glucose metabolism in the brain. By contrasting blood flow measures in closely matched tasks, such as silently reading nouns versus reading nouns out loud, it is possible to determine brain regions involved in various cognitive functions, such as the production of speech (Posner & Raichle, 1994).

Similarly, fMRI is frequently used to determine the brain areas that are metabolically active during different sorts of cognitive processes. The most commonly used method, blood oxygen level-dependent (BOLD) contrast imaging, takes advantage of the presence of paramagnetic deoxyhemoglobin in the blood to track changes in the amount of oxygen in the blood that result from brain activity (Kwong et al. 1992). Because fMRI scans are completely non-invasive and can be done in clinical scanners available in most hospitals (though BOLD imaging does require minor modifications to most clinical MRI scanners), fMRI has largely supplanted PET as the method of choice in cognitive neuroscience.

In keeping with its use to localize brain regions involved in various cognitive processes, the spatial resolution of fMRI is excellent. When used in the appropriate paradigms, resolution can extend down to less than a millimeter, enough to separate ocular dominance columns. However, because the change in blood oxygenation levels is not an immediate response to neural activity, the temporal resolution is considerably less than that in electrophysiological techniques such as event-related potentials.

3.2.3 *Event-related potentials*

Another source of information about brain activity is electrical recording from the scalps of humans. By recording participants' brain waves on an electroencephalogram (EEG) and averaging across time-locked events, the event-related potential (ERP) is obtained. The resulting waveform can be divided up into components and correlated with various aspects of the information processing required by the event. Early patterns in the waveform, occurring as quickly as 50 ms after the presentation of a stimulus item, have been related to aspects of perceptual processing. Components occurring later, at about 300 ms after the presentation of a stimulus item, are associated with the subjective perception of an improbable or surprising event (Donchin 1979). Of particular interest to linguistically oriented researchers, the N400 component, a negative-going wave with onset approximately 400 ms post-stimulus, has proven to be correlated with certain aspects of semantic processing. Because the ERP taps real-time processing of sentences it is ideal for testing processing models of pragmatic phenomena (see Coulson 2004 for review).

3.3 Computational techniques

3.3.1 *Computational modeling*

Overall, the dominant research paradigm in cognitive science is computational modeling of cognitive processes. Computational models provide a medium for integrating knowledge of disparate cognitive phenomena gleaned from experimental studies. By the same token, modeling provides a medium for integrating knowledge of cognitive processes gleaned from multi-disciplinary studies. Moreover, cognitive phenomena are not static but dynamic processes that change in response to changes in cognitive agents' external environments and internal states. Computational models are especially well-suited for capturing this dynamic aspect of cognition.

Probably the most useful reason for building computational models is that they necessitate a fully explicit account of the representations and processes that explain a given cognitive phenomenon. In the course of coding up a model, the cognitive scientist inevitably discovers aspects of a problem that s/he might never have encountered had s/he not endeavored to provide as explicit an account as required by a computational model.

Additionally, a sufficiently complicated model of cognitive process will often yield predictions about empirical manifestations of the phenomenon that may not have been obvious at the outset of the investigation. Used correctly, computational modeling and empirical investigations can be employed in a symbiotic manner where data from experiments inform the original model; the development of the model leads to elaboration of the theory, which in turn yields predictions testable by empirical methods. The results of subsequent experiments are gradually incorporated into the model.

The disadvantage of modeling is that coding up a model usually means accepting the observation and recording of behavioral activities such that systematic and/or local sources of data are overly simplified because of the need to obtain 'clear' or unambiguous, discrete measures. Consequently, many computational models of natural language processing are not sensitive to pragmatic aspects of language, especially subtle, situation-specific contextual clues. The incorporation of microgenetic aspects of context into computational models of language development and competence remains a challenge for cognitive science.

3.3.2 *Corpus research*

Another use of the computer is as a research tool, as when linguists use computers to investigate the statistical properties of electronically stored records of written and spoken text. The use of corpora allows the linguist to make objective statements about the existence of certain language phenomena, as well as their relative frequency in certain sorts of texts. Because a number of models of language comprehension suggest speakers are extremely sensitive to the frequency of different sorts of linguistic information, psycholinguists often use corpora to make predictions about processing difficulty (MacDonald, Pearlmutter & Seidenberg 1994).

Due to the availability of electronic language corpora as well as the continual increase in computers' storage capacity and processing speed, corpus linguistics is one of the fastest growing subfields in linguistics. Historical linguists use corpora to track the emergence of word senses over time, while lexicographers use them to rapidly assemble examples of a word or phrase so as to categorize and quantify its different uses. In semantics, the corpus can provide an additional source of information about meaning besides the linguists' intuitions. Though many corpora do not include the sort of contextual information needed by researchers in pragmatics, the number of context-rich corpora is bound to increase so that this tool may soon be influential in pragmatics.

4. Issues

4.1 The mind–body problem

Modern cognitive science continues to explore traditional debates such as the mind–body problem, or the issue of how the relationship between the mind and the body, or brain, should be described. Indeed, a central focus of cognitive neuroscience is how the brain gives rise to mental activity. One promising avenue of research concerns the integration of social psychology and cognitive neuroscience to address the brain bases of affect and socio-emotional phenomena such as attitude change and stereotyping. On the other end of the spectrum are roboticists who study how the constraints and limitations imposed by the physical makeup of an organism's body contribute to its cognitive capacities.

Although long eschewed as an unscientific topic, the nature of consciousness has emerged in the last decade as a serious topic in neuroscience. For example, Crick & Koch (1997) suggested that conscious percepts result only when neural activity in distributed brain areas is synchronous. This suggestion was offered as a solution to the so-called *binding problem*, which results because though particular brain regions have been identified with the processing of certain aspects of visual experience (e.g. shape processing, color processing, motion processing), neuroscientists have had less success in locating brain regions in which all of this information comes together. Because oscillatory processes are found throughout the brain, Crick & Koch's suggestion that binding might occur via synchronous oscillations among multiple brain areas is an ingenious solution to this problem and has prompted a great deal of research.

Many important discoveries in cognitive science involve the importance of unconscious mechanisms in cognitive processes. For example, Milner & Goodale (1998) report a patient with damage to the temporal lobe who can perform visually guided actions without visual awareness. Analogously, damage to the medial temporal lobe produces amnesics whose explicit, declarative memory is profoundly impaired, while their performance is largely spared on implicit, nondeclarative memory tasks. Given a list of words to study, such patients perform poorly on cued recall tasks that require them to remember the experience of seeing the words, but normally on priming tasks where their better performance on studied words suggests the study task did indeed have a lasting effect on their brains (Squire & Zola-Morgan 1988). In language processing as well, most of the phonological, syntactic and semantic processes operate below the sphere of consciousness. Even high-level pragmatic phenomena such as metaphor and framing in which we are quite aware of the end product have important unconscious components (Coulson 2001; Fauconnier 1997; Lakoff & Johnson 1998).

4.2 From genes to behavior

Another major axis of research in cognitive science concerns the relationship between genes and behavior, or how biology, development, and experience interact over the course of development. Like many issues in cognitive science, this controversy has its origins in philosophy but has been transformed by technological and empirical advances in the natural and social sciences. The philosophical dispute in this case is one between the rationalists, who hold that the nature of mind itself is the main determinant of experience with reality, and the empiricists, who embrace the idea that all knowledge results from experience in the world. One formulation of this issue is the competing influence of nature and nurture on cognitive development. However, as we have learned more about genetics on the one hand and brain development on the other, it has become clear that this is an ill-posed formulation of the issue.

The problem with the traditional formulation is that biological and environmental factors are presumed to be distinct forces whose influence can be measured and compared, analogous to the hardware and software in a computer. However, the physical basis of learning is experience-dependent changes in syntaptic strength that alter the ability of one neuron to influence the activity of those to which it is connected. Thus learning does not simply result in the accumulation of knowledge, but also to changes in the learning mechanism. While we often think of brain maturation as causing changes in behavioral ability, functional experience in the world is itself a causal factor in brain maturation. Further, neither the brain nor the environment is static as the developing child will attend to different aspects of the environment at different stages in the maturational process (Karmiloff-Smith 1998).

Much research in this area focuses on developmental disorders such as Williams Syndrome that can be traced to particular genetic alterations. However, because developmental pathways involve interactions between biology and experience, as well as interactions across time, modern research in this area requires modeling the way that gene deletions impact cognitive and neural development over the entire course of the lifespan. Neuroscientists seek to identify the timing of gene expression and characterize its interactions with other genetic and environmental events, while neuropsychologists study the behavioral manifestations of developmental disorders in low-level impairments as well as their impact on higher cognition (Karmiloff-Smith 1998). These processes can be modeled computationally with constructive neural networks whose architecture can be altered as part of learning (Quartz 1999).

In addressing the issue of how biology interacts with social and cultural experience, the typical formulation involves equating biological factors with hardware, and culture with software. However, because the nature of mind is so incredibly experience-dependent, this analogy is not particularly apt. Similarities and differences in the mental abilities of people in disparate cultures reflect the dynamic interplay of cognitive development in a particular culture. Related issues are also addressed by the cognitive anthropologist who studies the ways in which immersion in a culture enables intelligent behavior that would otherwise be impossible. Because cultural experience is constitutive of mind, attention to cultural factors inevitably leads to generalizations about cognition (Shore 1996).

4.3 Representation and rationality

Historically, many of the most exciting debates in cognitive science have concerned the nature of representation (Bechtel 1998). For example, cognitive scientists' initial resistance to connectionist models was that they seemed to lack the symbolic representations necessary for a compositional system (Fodor & Pylyshyn 1988). Using reasoning dating back to Chomsky's objections to behaviorism, Fodor & Pylyshyn argued that the systematic and productive character of human behavior, especially linguistic behavior, can only arise from a compositional symbol system. Connectionists have replied that although the representations in neural networks are sub-symbolic, that is, a representation in which numerous elements cooperate to represent a single symbol, their distributed character has computational advantages of its own (Smolensky 1988). These advantages include robustness to noise and the capacity to generalize from a small set of exemplars.

Another dispute in cognitive science involved the representational format of mental imagery. Based mainly on the parsimony of a single, extremely powerful representational format, some cognitive scientists have argued that propositional representations underlie all cognitive processes, including mental imagery. Others have pointed to commonalities in the properties of perceptual processes and tasks that involve mental imagery to argue for the existence of analogue representations. Although advocates of propositional representation were correct that mental images are more abstract than mental pictures, evidence from neuroscience suggests that mental imagery exploits topographically organized brain areas, and is thus analogue in character.

A related debate concerns whether conceptual representations are modal or amodal in character. Traditionally, concepts have been considered to be symbolic, and thus arbitrarily related to the things they represent. However, motivated by the constraints of the biological underpinnings of the mind in an organ evolved to support physical and social interaction in the world, a number of cognitive scientists have proposed that conceptual representations have some of the characteristics of perceptual representations. One such proposal is that schematic representations of perceptual experience are stored around a common frame that promotes schematized simulations that recruit neural machinery activated in perceptual experience from all modalities (Barsalou 1999). One appeal of these perceptual symbols is that they help explain the *intentionality* of our concepts, or how it is that the concept of a rock is "about" a rock, by grounding concepts in perceptual experience.

While these traditional disputes over representation involve specifically mental representation, other cognitive scientists have suggested that mental representations are not sufficient for a theory of cognition. For example, advocates of situated action theory argue that intelligent behavior is less the product of internal mental processes than the interaction of those processes with external social and historical factors that constitute the context of human action. The main determinants of intelligent behavior do not involve content-independent representational processes, but rather, embodied behavior profoundly affected by social interaction, historical influences, culture, and the environment. In a related approach, the theory of distributed cognition describes cognition as a process distributed across individuals, tools, and artifacts in the environment (Hutchins 1995).

One virtue of the distributed cognition framework is that it can help resolve the puzzle of how people are able to solve complex sequential problems with brains whose architecture seems best suited for categorization and pattern completion (Clark 2001). By using a pen, a piece of paper, culturally transmitted numeric symbols and algorithms for multiplication, it is possible to transform a difficult multiplication problem to a sequence of simpler steps that involve pattern completion and the temporary storage of information via our marks on the page (McClelland, Rumelhart, Smolensky, & Hinton 1986). Hutchins (1995: 155) notes that the use of these physical and cultural tools "permit the [users] to do the tasks that need to be done while doing the kinds of things people are good at: recognizing patterns, modeling simple dynamics of the world, and manipulating objects in the environment."

Yet another approach to cognitive science involves no mental representations, whatsoever. Dynamic systems theory involves importing formalisms used in physics to describe multidimensional phenomena that change over time in order to characterize cognitive processes, especially adaptive behavior that involves the interaction of neural processing, bodily action, and environmental forces. These researchers argue that representation is not a useful concept, and that cognitive scientists should instead focus on the relationship between the organism and the environment, and on the sub-representational dynamics of the system (e.g. van Gelder & Port 1995). However, others have argued that even advocates of dynamics systems theory use a notion of an information-carrying state that is tantamount to representation (Bechtel 1998; Markman & Dietrich 2000).

5. Cognitive science and pragmatics

5.1 Definition

The study of pragmatics has revealed the extent to which language use depends upon users' assumptions and inferences about each other, awareness of the particular context of speaking, general background knowledge, and even tacit assumptions about language use itself. The way speakers utilize this vast array of linguistic, non-verbal, and inferential resources constitutes an important set of cognitive phenomena. The investigation of these phenomena by researchers in pragmatics thus falls, by definition, under the rubric of cognitive science. Moreover, the close relationship between language and reasoning that is inherent in pragmatic phenomena presents a number of possibilities for fruitful interaction between researchers in pragmatics and those in other branches of cognitive science. Below we explore connections, both actual and possible, between the methods, interests, and issues of pragmatics and the rest of cognitive science.

5.2 Methods

Pragmatics presents the cognitive scientist with a number of linguistic facts, a set of categories for classifying those facts, and methods for testing competing explanations of those phenomena. Proposals in cognitive science should be able to account for phenomena already identified and explained by pragmatics. Moreover, proposals in pragmatics must also be answerable to relevant critiques from other cognitive scientists.

Pragmaticists and cognitive scientists, then, might work together to account for the ways in which context constrains interpretation. The differences between them lie mainly in emphasis. For example, the pragmaticist might ask how general properties of cooperative interaction affect language structure and use, while the cognitive scientist might invert the question by asking what we can learn about general properties of cooperative interaction from language.

By working together, findings from different perspectives can serve to constrain theories about language in context. Indeed, this is the goal of researchers in the new field of experimental pragmatics that draws on methods from pragmatics, psycholinguistics, and the study of reasoning to address the relationship between language and thought in pragmatic phenomena (Noveck & Sperber 2004).

5.3 Issues

Researchers in pragmatics share an interest with the rest of cognitive science in the issues described above. With respect to the mind–body problem, the neural instantiation of pragmatic processing is certainly of interest, as well as the extent to which pragmatic processing is conscious. The dynamic relationship between genes and behavior has also piqued the interest of researchers in pragmatics, as Sperber & Wilson (2002) have proposed the existence of a genetically specified meta-communicative module. Moreover, questions about the intentionality and the format of mental representations are at the heart of pragmatics and cognitive science alike. At issue is whether physical, social, and cultural aspects of context are discreet inputs to a process for the computation of meaning, or whether they constitute resources used in a continual, dynamic, interactive process of meaning construction.

5.4 Convergent interests

5.4.1 *World knowledge and cultural knowledge*

Pragmaticists and cognitive scientists alike are interested in how background knowledge is represented and how it is brought to bear on the interpretation of utterances. Cognitive scientists have suggested that background knowledge is represented in hierarchical attribute-value structures, known as frames, scripts, and schemata. The term frame is used to characterize background knowledge about objects, and includes slots which may be filled either through a slot-filling process or with default values. Default values consist generally of the most typical and/or the most frequent filler for each slot and are invoked in the absence of other information. Scripts represent stereotyped sequences of events such as going to a restaurant, and contain slots that are either filled by binding the particular fillers manifest in the situation at hand, or by instantiating the default value for any particular slot. Schemata, a similar concept in psychology, have been proposed to underlie perception, planning, and memory for events. Schemata have also been used to explain human ability to make inferences in complex situations, to make default assumptions about unmentioned aspects of situations, and to make predictions about the consequences of actions.

Cultural models are frames, scripts, and schemata shared by members of a given society. Cognitive anthropologists who study cultural models are engaged in elucidating the organization of this vast knowledge base and linking it to what is known about human reasoning abilities. Cultural models are used in a variety of cognitive tasks including the formulation of plans and goals, interpretation of the actions and goals of others, and talk about human activity. Research on cultural models has implications for theories of lexical semantics, metaphor, polysemy, hedging and other linguistic phenomena. It also has important implications for the theory of culture, and the role of culture in reasoning, problem solving, and evaluating the behavior of others. Moreover, researchers in pragmatics can look to cultural models as providing a framework for describing the cultural assumptions essential to making the correct inferences required for reference, illocutionary force, politeness, and implicature.

5.4.2 *Mappings*

Besides background knowledge such as that represented in frames, schemata, and cultural models, meaning construction requires a substantial degree of mapping between cognitive domains. The importance of mapping is especially prominent in mental space theory (Fauconnier 1995, 1997), in which the process of meaning construction involves partitioning the representation of sentence meaning into domains or spaces. Although the discourse as a whole may contain contradictory information, each space functions as a distinct and logically coherent knowledge base. For example, partitioning a statement like *Six months ago John was in perfect health, but now he's on the brink of death* would start by dividing its information into two spaces: one for six months ago and one for the present time. Each space is internally coherent and together they function to represent all of the information contained in the original sentence. In contrast to traditional approaches to meaning construction, the bulk of the cognitive work involves mappings and correspondences between domains rather than the derivation of a logical representation of sentence meaning.

Mappings play a central role in the process of meaning construction, and can be divided into four categories: projection mappings, pragmatic function mappings, schematic mappings, and space mappings. Projection mappings involve the mapping of abstract structure from one domain onto another, as in a metaphor. In order to understand metaphoric use of language, the listener must map features of the source domain onto features of the target domain. The second type of mappings is pragmatic function mappings, such as those employed in metonymy. Pragmatic functions (Nunberg 1978) map objects from one category onto objects in another so that one term can be used to refer to the other. For example, authors are often mapped onto the books that they write, enabling us to say things such as, *I was up all night reading Searle*. Third, schematic mappings involve mapping aspects of a particular situation onto more generic frames to interpret them. Schematic mapping is also involved in structuring mental spaces with frames by setting up elements in spaces that correspond to the slots in the frame. Finally, space mappings serve to link mental spaces set up in discourse.

5.4.3 *Conceptual integration*

An exciting upshot of these developments is the finding that cognitive processes that underlie meaning construction in the most banal cases are also exploited in creative thought and expression. Cognitive scientists have found that the semantic and pragmatic levels of meaning construction also operate in general reasoning, narrative structure, and other high-level aspects of communication. For example, Nunberg (1978) has demonstrated that 'purely denotational' utterances are most likely interpreted via strategies very similar to those used in the interpretation of indexicals. Moreover, metaphor, once thought to be a mere rhetorical flourish, has surfaced in recent decades as involving cognitive processes fundamental to language change, analogy, problem solving, scientific reasoning, concept learning as well as creative language use.

Fauconnier & Turner (2002) argue, similarly, that conceptual integration, or blending, processes operate in the creative construction of meaning in analogy, metaphor, counterfactuals, concept combinations, and even the comprehension of grammatical constructions. At its most abstract level, conceptual blending involves the projection of partial structure from two or more input domains and the integration of this information in a new mental space known as a *blend*. When the information in each of the inputs is very different from one another, this integration can produce extremely novel results. However, there are many cases that involve the projection of partial structure and the integration of this information that yield predictable results. Blending processes depend centrally on projection mapping and dynamic simulation to develop emergent structure, and to promote novel conceptualizations, involving the generation of inferences, emotional reactions, and rhetorical force.

Conceptual integration processes have been argued to reduce the force of classic critiques of frame-based comprehension systems (Coulson 2001). One such criticism is that viewing frames as central components of language and reasoning presents certain problems, such as the gap between the simplified nature of frames and the complex nature of the tasks for which they are employed (Brachman 1985). Similarly, there is a tension between the static nature of traditional representational structures and the flexibility and diversity evident in people's speech and behavior (Shore 1996). However, the addition of mapping, frame-shifting, and conceptual blending processes makes it possible to construe meaning construction as a dynamic process in which speakers are continuously and creatively building and blending frames and cultural models, as opposed to simply retrieving and instantiating them.

5.5 Conclusions

Investigations in pragmatics and other areas of cognitive science have a shared heritage in philosophy. Besides addressing philosophical problems, this shared heritage has involved the use of analytic tools such as logic and other formal systems. However, there has been a subsequent shift towards the incorporation of socio-cultural influences on language and cognition in general. Investigations of meaning construction reveal the centrality of conceptual integration and mapping processes to semantic and pragmatic language understanding, as well as in other verbal and non-verbal reasoning phenomena. In sum, we have noted the relevance of pragmatics research to fundamental issues in cognitive science and pointed to a number of research interests shared by pragmatics and other areas of cognitive science.

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Comprehension vs. production

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1. Introduction

Language allows us to express and communicate our thoughts to others. Using language to communicate these thoughts relies on our abilities to both produce and to comprehend language. That is, without someone who can comprehend language (the 'listener'), someone producing an utterance (the 'speaker') won't be able to communicate thoughts via that utterance. Luckily, each one of us is both a speaker and a listener. Both the dependency between production and comprehension for communication and the fact that we all have both abilities, leads to a central question in language research: how are the two processes related? In other words, is going from thought to language and from language to thought, accomplished by a single system working in two directions, or by two separate systems? Most of the research on this question comes from the domain of psycholinguistics, primarily because of the focus on intermediate mental representations and processes.

Traditionally, psycholinguistic research has treated production and comprehension as independent systems, each with its own set of representations and processes. Perhaps the most influential findings that contributed to this traditional view were the discoveries of two functionally and anatomically distinct aphasias (Lichtheim 1885). Patients with damage to Broca's area are described as having impaired language production abilities, but relatively intact comprehension. Their speech is characterized as being broken and telegraphic, lacking function words and containing many articulatory disfluencies. In contrast, patients with damage to Wernicke's area are characterized as having impaired language comprehension. Their speech is fast, fluent, and grammatical, but lacking in true content or meaning. Additionally, Wernicke's aphasics have severe difficulties in their comprehension abilities. Further evidence supporting the dissociation between production and comprehension comes from studies of language development. Generally, comprehension abilities develop prior to production abilities. Children typically understand words before they begin to produce those same words (Benedict 1979).[1]

Production and comprehension also differ with respect to the local processing problems that they must solve. This is most easily demonstrated by considering the input to

1. Fraser, Bellugi, & Brown (1963) have argued that syntactic abilities follow a similar pattern of development.

each process. Production begins with a thought or message to be conveyed. The non-linguistic representation corresponding to this message must then be mapped onto corresponding linguistic representations (e.g., words). These linguistic representations must then be correctly ordered (e.g., phrases and clauses), and be translated into articulatory commands. Along the way, the speaker is in control of the input (the speaker knows the message to be conveyed) and outputs (what actually gets said). That is, speakers determine the content of the utterance, the speed of the utterance, and what the intended effects of the utterance are to be. The situation for the listener is quite different. The listener is not in control of the input to the comprehension system. The listener's task is to interpret the utterance and to attempt to recover the speaker's intended message. The problem for the listener is that ambiguities may arise at nearly every step of the process, during interpretation of the acoustic input, retrieval of the appropriate words and their meanings, the construction of the appropriate syntactic representation, and finally, the construction of an overall integrated interpretation. So, while on the surface, comprehension and production may appear to be the same sets of processes acting in opposite directions, the two systems must resolve different problems along the way, which may involve very different processing mechanisms and representations.

However, while production and comprehension do have a number of important differences, the two processes also have a number of parallels. Perhaps the most obvious parallel is that production and comprehension share the common goal of communication. They also appear to use similar kinds of linguistic representations (Garrett 1982a, 1982b). Evidence from a variety of sources, including analyses of speech errors (e.g., Fromkin 1973; Garrett 1980), experimental studies of production (e.g., Bock 1986; Bock, Loebell, & Morey 1992; Dell 1986, 1998; McKay 1987; Levelt 1989), and studies of word recognition and sentence comprehension (e.g., Frazier 1982; Patterson & Coltheart 1987; Schreuder et al. 1990), suggest that many of the representations used for producing and comprehending language correspond to formal linguistic representations (e.g., phonemes, morphemes, open and closed class words, phrases, and clauses). It seems possible, if not likely, that since both production and comprehension have similar goals, and work with similar kinds of representations, these representations and the processes that manipulate them, would be shared.

The following discussion focuses on three areas of recent psycholinguistic research that has examined the extent to which production and comprehension share mental representations and processes. The first section focuses on our mental lexicons. The second focuses on syntactic representations and processes. The final section examines impact of comprehension on production with respect to how speakers and listeners cooperate for communication. Clearly these three sections do not cover all of the relevant psycholinguistic research bearing on this issue, however they do demonstrate the wide range of representations and processes for which the production versus comprehension issue is relevant and currently being examined.

2. The structure of the lexicon

One central question in psycholinguistic research has been to determine how lexical information is mentally represented. In particular, a great deal of research has focused on how different kinds of lexical information (i.e., the form, syntax, and semantics of words) are represented within the lexicon. However, surprisingly little research has examined the question of whether production and comprehension share a common set of lexical representations, or whether there are separate sets of representations. This question has been overlooked in large part because most theories of lexical access have focused on either comprehension (e.g., Becker 1976; Besner & McCann 1987; Forster 1976), or production (e.g., Dell 1986; Garrett 1988; Levelt 1989; Roelofs 1992), while ignoring the other.

One can imagine three possible models that could characterize the relationship between the lexicon and the processes of production and comprehension. One possible model is the *distinct lexicons model*, in which language production and comprehension are separate processes, each with its own set of lexical representations, meeting only at the non-linguistic message level. The strongest support for this kind of model comes in the form of dissociations in language impaired patients (e.g., Caramazza 1991; Funnell & Allport 1987; Shallice 1988). The second model is the *shared lexicon model* in which production and comprehension involve one set of representations and processes, which operate in either direction. For example, recent interactive activation models (e.g., Dell 1988; MacKay 1987a; Stemberger 1985) typically assume this model to motivate bi-directional flow of information. *The mixed lexicon model* is a hybrid of the first two models. This model proposes that production and comprehension processes, share some, but not all levels of lexical information (e.g., Allport 1984; Levelt 1989; Monsell 1987). This mixed lexicon model emphasizes the fact that the lexicon is typically not assumed to be just a mental listing of words. Rather, the lexcion is a richly structured set of levels of representations which correspond to different kinds of lexical information (e.g., form, syntactic, and meaning). The current issue, of overlap between production and comprehension, is relevant to each of these representational levels.

Recent psycholinguistic models of production propose that there are two levels of lexical representations. One level corresponds to semantic/syntactic representations of words, often referred to as 'lemmas' (Kempen & Huijbers 1983; Levelt 1989). The second level corresponds to form representations, often referred to as lexemes (e.g., phonological and orthographic representations). Thus, during production, the first task that a speaker must face is to map a non-linguistic concept onto the best fitting lemma. Following the selection of a lemma, the next task that the speaker faces is the selection of the appropriate lexeme that corresponds to the lemma. Evidence supporting this two-stage model comes from a variety of sources, including analyses of speech errors (e.g., Garrett 1988), the tip-of-the-tongue experience (e.g., Vigliocco, Garrett, & Antonini 1997), experiments on picture naming (e.g., Schriefers, Meyer, & Levelt 1990), and evidence from language pathologies (e.g., Badecker, Miozzo, & Zanuttini 1995).

A similar distinction exists in models of comprehension (see Balota 1990 for a review). Generally, comprehension models propose separate word form and meaning levels of representations. It is interesting to note that, unlike production models, comprehension models typically overlook the issue of representation of lexical syntactic information. Some models assume syntactic information at the word level, while others assume it at the semantic level. This oversight may, in part, be linked to the development of two (largely separate) traditions of research and theory: word recognition and sentence parsing. The former tradition has focused on the representation and access of words, while the latter has focused on the construction of sentence-sized syntactic structures.

Most of the research that has examined the lexicon has focused on how the different levels of lexical information interact during either production or comprehension. In production for example, there is a large debate over whether phonological processing may begin prior to the completion of semantic processing (e.g., Cutting & Ferreira 1999; Dell & O'Seaghdha 1991; Dell & Reich 1981; Levelt 1989; Levelt et al. 1991; Peterson & Savoy 1996; Schriefers, Meyer, & Levelt 1990; Starreveld & La Heij 1995). A similar debate exists in the comprehension literature (e.g., Folk & Morris 1995; Grainger & Ferrand 1994; Van Orden 1987; Van Orden, Johnston, & Hale 1988). Recently there have been a few attempts to examine the representational issue with respect to the lexicon and its relationship to production and comprehension.

Shallice, McLeod & Lewis (1985) examined the issue with a series of dual task experiments in which speakers simultaneously named visually presented words, while also monitoring an auditorily presented stream of words for proper names. They demonstrated that both tasks could be performed with little interference, supporting a separate lexicons view. Monsell (1987) using a repetition priming task,[2] predicted that if production and comprehension share phonological representations, there should be repetition priming from the primes involving production to the comprehension probes. He found results consistent with a shared representation model (also see Ferrand, Grainger, & Segui 1994; Gipson 1986; Stuart & Jones 1996): All of the prime tasks that required the generation of a phonological or orthographic representation resulted in speeded auditory lexical decisions[3] on the probe trials.

2. These tasks involve two presentations of the same word. The initial presentation is called the *prime* trial and the second presentation the *probe* trial. The typical result is repetition priming: a response to the probe trial is faster when it is preceded by an identical prime trial compared to when the probe is preceded by an unrelated prime word.

3. In a lexical decision task, participants make a speeded decision about whether a string of letters (or sounds) constitute a real word or not.

One problem with the Monsell experiments is that they all use a form of repetition priming which cannot distinguish between the lemma (meaning) and lexeme (form) levels of representation. In other words, the experiments support a model in which some lexical representations are shared by production and comprehension (though it is unclear whether these include lemmas, lexemes, or both). To examine this issue, Cutting (1997) performed a series of experiments using a variation of the priming task with word-pairs as primes and pictures as probes. The word-pair prime trials consisted of two words, one produced and the other ignored. The logic of the task was that produced words were both comprehended and produced, but ignored words were only comprehended (for a similar argument see Underwood 1976; Underwood, Parry, & Bull 1978; Underwood & Thwaites 1982). If lexical representations are shared, then both produced and ignored related primes should result in priming of probe picture naming. Priming was observed for both produced and ignored primes when the prime and probe were identical (e.g., both producing and ignoring the prime word "*lion*" sped the naming of a picture of a lion). Similar results were found when the prime words were semantically related (e.g., prime: tiger; probe: lion). However, when the prime words were phonologically related to the probe picture priming only occurred following produced primes (e.g., saying "*liar*" before naming a picture of a lion resulted in priming, but ignoring liar had no effect). Taken together, these results support a model in which the semantic representations (lemmas) are shared by production and comprehension, while the form representations (lexemes) are not.

Zwitserlood (1994) used two different tasks to examine the same question. To examine production, she used the picture-word interference task. Speakers named pictures in the presence of distractor words (presented prior to or just after the onset of the picture). If the distractor word was phonologically similar to the name of the picture, picture naming was facilitated. This was true if the phonological similarity was from real word distractors (e.g., towel), word fragment distractors (towe), or pseudowords (towes). To test comprehension, Zwitserlood presented listeners with a visual word to which they made a lexical decision. As in the production task, listeners heard phonologically related distractor words while performing the lexical decision. The results for the comprehension task were qualitatively different from those for the production task: Only word fragment distractors sped lexical decision times; real and pseudowords had no effect. Like the Cutting (1997) results, these results support a model of the lexicon in which production and comprehension have separate word form representations. However, Zwitserlood also proposed an alternative explanation for the pattern of results. The observed differences may reflect a processing difference rather than a representational difference between comprehension and production. That is, the selection processes involved in comprehension of words may be different from those involved in the selection of words for production and these processing differences may be responsible for the pattern of results. Clearly, more research is needed to tease these two possibilities apart.

The evidence to date supports the mixed model of the lexicon. The view that emerges is that semantic representations are shared, but form representations may not be. Given the role of word form information, perhaps this should not be too surprising. The word form levels of representation are most closely tied to a diverse set of language modalities. On the production side, form representations are mapped onto articulatory representations (written and spoken). However, in comprehension, form level representations are selected based on acoustically and visually based representations. Perhaps, this diversity of processing demands on form information by the two systems is what dictates separate sets of representations.

3. Building syntax

Another similarity between production and comprehension relates to the use of syntactic information. Once we retrieve lexical representations, we need to start figuring out how to put them together. In production, after we have mapped our message level representations onto lemmas we need to map them onto a linear series of words. One of the hallmarks of human language use is the flexibility of the system (there are many ways to say essentially the same thing). However, the order of the words in our utterances is not arbitrary, but must conform to the grammatical rules of the language spoken. In fact, even when we produce errors, the errors typically follow certain grammatical constraints (Garrett 1988). In comprehension, the order of the words is pre-determined (by the speaker), but the syntactic structure is not. Often, a particular linear sequence of words is ambiguous with respect to the underlying syntactic structure. For example, the classic joke about the hunter on safari who claims that "*The trip was so unusual that I shot an elephant in my pajamas. How he got into my pajamas I'll never know*". The joke relies on the fact that the prepositional phrase *in my pajamas* may modify either the hunter or the elephant depending on which syntactic structure is built during comprehension. The impact of this ambiguity is magnified when one considers the incremental nature of comprehension. That is, if structure is built as words arrive in the system, syntactic decisions must be made based on partial information, rather than on the entire sentence. Clearly, both production and comprehension involve the creation of syntactic structures, however the question of whether or not the two systems share processes or representations still remains.

How do current models of production propose that linear order is determined (see Bock & Levelt 1994; Garrett 1988)? Suppose that you, the producer, see a bee stinging a man and you tell a listener what you saw. At the message level, the event is parsed into event roles (agent = BEE, patient = MAN, action = STING). This information leads to the retrieval of a set of lemmas that best correspond to the semantic constraints of the message. Each lemma has information about the arguments that it requires (e.g., STING needs a subject and an object). Next, functional roles (e.g., subject, object) are assigned to the retrieved lemmas, according to a grammatical hierarchy (Keenan & Comrie 1977) and the conceptual accessibility of the retrieved lemmas (Bock 1986 1987a 1987b; Bock & Warren 1985; Bock, Loebell, & Morey 1992). That is, whichever lemma is most accessible will be assigned the highest functional role (e.g., subject). Once the functional roles are assigned then the syntactic structure building process can incrementally begin making the syntactic frame (Ferreira 1996). After the syntactic frame is built, retrieved lexemes are inserted into syntactic slots in the frame and the representation can be passed onto the articulation processes.

Syntactic structure building in comprehension begins at the other end. The problem for the listener is to determine the correct syntactic structure of an utterance that enters the system one word at a time. As each word comes in, decisions must be made with respect to how that word should be integrated with the overall syntactic representation being constructed. These decisions include determining what the grammatical class of each word is (e.g., is *train* a noun or a verb) and how the word fits into the evolving structural syntactic frame of the sentence. Most of the research examining how this process works has focused on the issue of how different levels of information within the comprehension system interact. For example, can prior contextual information or semantic information help resolve lexical ambiguities or guide the initial parse of a sentence.[4]

Largely, the research on syntactic structure building has focused entirely within either production (e.g., Bock 1986) or within comprehension (e.g., Frazier, et al. 1984). Very little research has explored the question of whether production and comprehension share syntactic processes and representations that are larger than the level of individual words (Frazier 1982; Garrett 1982). One area of research that does have the potential for addressing this issue is syntactic priming (e.g., Bock 1986, Bock & Loebell 1990). Syntactic priming is the repeated use of particular syntactic structures. The phenomenon has been studied primarily within production. For example, Bock (1986) presented speakers with sentences and pictures. If the speaker heard a sentence, they repeated it (the prime); if they saw a picture they described it (the probe). Bock found that the picture descriptions often had the same syntactic structure as that of the preceding prime sentence. A similar phenomenon has also been observed in a few studies of comprehension. Frazier et al. (1984) presented readers with sentences with conjoined clauses and found that reading times on the second clause were sped up if the second clause had a similar syntactic structure as the first clause.

Syntactic priming has also been demonstrated between comprehension and production. Levelt & Kelter (1982) called shop keepers in the Netherlands and asked them what time their shop closed. The responses given by the shop keepers make clear that the syntactic structure of the questions that they comprehended influenced the structure that they used in their

4. For extensive reviews of this research see MacDonald, Pearlmutter, & Seidenberg 1994; Frazier & Clifton 1996).

own produced answers. Recently, Pickering and Branigan (1995; reported in Branigan et al. 1995) report the results of syntactic priming between comprehension and production in a laboratory setting. In this study, they presented speakers with a written sentence completion task in which, each critical sentence fragment (e.g., "*The judge gave…*") was preceded by a prime sentence with a particular syntactic structure (e.g., "*The victim showed his injuries to the judge*"). Completions of the critical sentences were likely to have similar syntactic structures as their prime sentences.

The results of Levelt & Kelter (1982) and Pickering & Branigan (1995) suggest that some part of the building of syntactic structures is shared by comprehension and production. However, the results don't by themselves distinguish what is shared: processes, representations, or both. Pickering & Branigan (1995) argue that their results favor a model in which the two systems probably do share syntactic representations. Syntactic information is represented independently of the syntactic processing mechanisms used in comprehension and production (see also Frazier 1982). That is, the representations of syntactic information about the words themselves are represented such that they are available to both comprehension and production mechanisms.

The results of Frazier et al. (1984), demonstrate that listeners may benefit from the repetition of structure. It has been suggested that the purpose of producers reusing syntactic structures is to make comprehension easier for the listener. The results of Bock (1986) and Levelt & Kelter (1982) demonstrate that the persistence of syntactic structures may be due to processes entirely within the production system rather than a listener accommodation strategy. However, there are other things that speakers may do to help listeners. The final section of this review focuses on how the problems of a listener may influence the production processes of a speaker.

4. The speaker as a listener

A speaker produces an utterance for the purpose of communication. To this end, the speaker must not only be able to correctly produce the intended utterance, but also the utterance must be in a form that is comprehensible to the listener. There are many examples in the pragmatic literature that demonstrate that speakers adjust the utterances to make comprehension easier for the listener. Some of the more subtle adjustments that speakers make include using less complex structures, including information that may not be easily inferred in a particular context, marking given-new information, using pauses and hesitations to signal potential troubles, and using intonation information to highlight portions of the utterance. Some recent psycholinguistic research has focused on the mechanisms by which this cooperation between speakers and listeners may be achieved. I will focus on two of the main approaches, the monitor model and the listener model.

One approach has been to assume that an utterance is planned based primarily with respect to production constraints (e.g., conceptual & lexical accessibility, functional assignment, syntactic priming). However, after the initial planning, but prior to articulation, the speaker's own comprehension system may be used as a monitor. That is, because a speaker is also a listener, the speaker may be able to use his or her own comprehension system to monitor their intended utterances. Levelt (1989) proposed that the monitor can evaluate the speech output for a number of different levels of criteria (e.g., social acceptability, does it adequately convey the message, are the correct words selected, does it sound correct, etc.). If the utterance is found faulty, then articulation may be halted and the utterance may be repaired.

Evidence in favor of the monitor view comes primarily from research examining overt and covert speech errors. Dell & Reich (1981) demonstrated that there is a lexical bias such that phonological errors are produced as wrong but actual words at a rate greater than one would expect based on chance alone. Levelt (1989) proposed that this lexical bias effect may be explained by a bias of the monitor such that it is more likely to detect non-word errors than word errors. Baars, Motley, & MacKay (1975) replicated the lexical bias effect using an experimental procedure designed to elicit phonological errors. Motley, Camden, & Baars (1981), used the same phonological error elicitation methodology and demonstrated that speakers were less likely to make slips that were designed to result in socially inappropriate utterances (e.g., *tool kits* slipping to *cool tits*) compared to similar but acceptable slips (*tool carts* slipping to *cool tarts*). Baars (1977; reported in Mattson & Baars 1992), found similar results for phrasal slips (e.g., *she rubbed her nose and picked a flower* slipping to *she picked her nose and rubbed a flower* was less common than *she touched her nose and cut a flower* slipping to *she cut her nose and touched a flower*). These results suggest that the monitor is flexible, sensitive to several levels of analysis, including lexical and pragmatic.

Not all errors are overt, some errors may be detected by the monitor and repaired. These repaired errors are covert errors, the presence of which may be signaled by disfluencies in the speech stream. These disfluencies include: false starts, the use of editing expressions (e.g., "*er*", or "*I mean*"), and long pauses (Nooteboom 1980). Levelt (1983) suggested that the disfluencies reflect the action of the monitor, sending a signal to the articulator signaling it to stop as soon as trouble arises (e.g., lexical retrieval failure or the detection of an outright error). Disfluencies also include filled pauses like "*er*", "*I mean*", or "*that is*." These editing expressions may act as a signal to the listener that trouble has arisen, in a sense asking them to be patient and wait for a correction (e.g., Fox Tree 1995). For example, the word *the* is sometimes pronounced /thuh/ while at other times it is pronounced /thiy/, and that the difference may be a signal to the listener that there was a problem. Fox Tree & Clark (1997) found that noun phrases beginning with a /thiy/ were ten times more likely to contain a disfluency than a phrase beginning with a /thuh/. Results like these suggest that the monitor may act in a cooperative fashion by both signaling the need for a revision of the utterance, and giving the listener advanced warning about what kind of revision is forthcoming. Levelt (1989) also suggested that the monitor may be involved with keeping track of comprehension difficulty signals from the listener, reformulating utterances to dispel the difficulty. As evidence of this, Levelt (1983) demonstrated that syntactic revisions operate in such a way as to preserve the well-formedness of the utterance, probably, so that it is easier for the listener to understand the final utterance.

Another approach to the issue of how speakers cooperate with listeners assumes that the speaker takes into account a model of the listener when preparing an utterance. That is, speakers maintain a set of beliefs, or common ground (Clark 1996 for an extensive review) about what they believe that their listeners know. So the coordination between speaker and listener can be accomplished by taking the listeners perspective into account when preparing an utterance (e.g., Clark & Haviland 1977; Clark & Marshall 1981; Clark & Murphy 1982; Clark, Schreuder, & Buttrick 1983). For example, Keysar (1994) suggested that when formulating an utterance, the production system may consult a model of the listener which includes information about the social setting, the listener's assumed level of knowledge, and the common ground that the speaker and listener may share.

It should be noted that the monitor and listener model approaches are not mutually exclusive. It is certainly possible that both systems are in operation. For example, most of this perspective taking discussed above is probably associated with message level planning, but the existence of reformulations triggered by speaker cues and results like those of Motley et al. (1981) do suggest that the monitor may evaluate pre-verbalized utterances with respect to these levels of linguistic analysis.

Recently, there has been some research designed to tease apart how much of the listeners perspective is taken into account during the initial planning of an utterance compared to during the monitoring and repair process. Brown & Dell (1987, see also Dell & Brown 1991) presented speakers with short stories depicting characters performing different actions (e.g., a story about a robber who stabs a man who interrupts the break-in). The speakers were then asked to report, in their own words, what happened in the story. In the stories, Brown and Dell manipulated the typicality (e.g., a knife [typical] versus an ice pick [atypical]), and relative importance (whether fingerprints were on the instrument [important] or on a dresser [less important] resulted in the capture of the robber) of the instrument used in the story. The authors also manipulated whether or not the speaker thought that the listener knew what the instrument was by presenting a picture that either did or did not depict the instrument. Of interest was whether the instrument was mentioned in the retelling of the story, and if it was, when it was mentioned. Generally, speakers mentioned atypical instruments more often than typical instruments, and importantly, this effect did not interact with the listener's knowledge factor. Brown and Dell proposed that typicality influences the initial planning of an utterance, resulting from the best-fit matching of the non-linguistic message representations onto lemma representations. That is, the concept of stabbing with a typical instrument (e.g., a knife) maps easily onto the lemma for STAB. In contrast, the concept of stabbing with an atypical instrument (e.g., an ice pick), may easily map onto the lemma for STAB alone, but instead requires the retrieval of additional lemmas (e.g., ICE PICK). This process is not influenced by a model of the listener, but is instead a part of the normal production process. On the other hand, listener's knowledge did interact with instrument importance, such that important instruments were mentioned more often when the listener saw a picture that depicted the instrument. However, this effect only occurred when the mention was in a separate clause that followed the verb. Brown and Dell proposed that this reflects the monitor and repair part of the production process rather than the initial utterance planning.

In a related experiment, Horton & Keysar (1996) presented speakers with objects on a computer screen. One object moved (target object) and another did not (context object). Speakers were asked to describe the scene such that a listener will be able to determine whether they saw the same or a different object move. Half of the speakers were told that the listeners would see the context object, the other half of the speakers were told that they would not. Additionally, half of the speakers were instructed to begin their descriptions quickly, while the other half were instructed to "take as much time as they liked." The results suggested that speakers in the unspeeded conditions took the listener's perspective into account when planning their utterances. That is, the speakers who thought that their listeners could see the context object, were much more likely to use a context related adjective in their descriptions than were those who thought that their listeners could not see the context object. A different pattern emerged with the speakers in the speeded conditions. These speakers did not appear to take common ground into account in their initial utterance planning. For these speakers, there was no difference in the use of context related adjectives between those who thought that their listeners could see the context object and those who thought that they could not.

The results of Brown & Dell (1987) and Horton & Keysar (1996) suggest that there may be limitations on how much information from a model of the listener is used in the initial planning of utterances. These results, together with results like production-to-production syntactic priming, highlight the possibility that many of the apparently cooperative accommodations that speakers make may in fact be accounted for by entirely production based mechanisms. While the overall effect of these apparent accommodations may appear to be the result of speakers attempts to make things easier for the listener, these effects may instead be the result of attempts by the production system to make production easier. That is, speakers may initially plan their utterance based on purely selfish principles, and later, via some kind of monitoring, make adaptations when needed.

5. Conclusions

Communication requires two sets of processes, comprehension and production. Lashley (1951) noted that "… the processes of comprehension and production of speech have too much in common to depend on wholly different mechanisms." In other words, while there are clear differences between comprehension and production, there are also some striking similarities. However, most of the psycholinguistic research on language use has focused on only one or the other system. In this chapter, I have identified three areas in which comprehension and production may overlap and I have briefly reviewed some of the recent psycholinguistic research that has examined whether comprehension and production depend on different mechanisms. The emerging picture suggests that Lashley was correct, comprehension and production appear to share some sets of representations (i.e., meaning and syntax), while other kinds of representations may be separate (i.e., form representations). However, the emerging picture is far from complete. There is clearly a need for much more research that examines both comprehension and production and the relationship between them.

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Connectionism

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1. Introduction

During the last decade, connectionism has increasingly received attention within a variety of research disciplines. In this contribution, we focus on the role of connectionist modeling within the domain of natural language processing (NLP) and, more specifically, on pragmatics. As a computational theory, connectionism has led to significant developments in modeling cognitive processes. Rumelhart & McClelland, in their influential two-volume handbook, characterize connectionist modeling as providing

> […] a mechanism sufficient to capture lawful behaviour, without requiring the postulation of explicit […] rules. (Rumelhart & McClelland 1986: 218)

The fact that connectionist modeling does not necessarily require the use of explicit rules and symbols, and that connectionist processing is inspired by neurophysiology, makes the connectionist paradigm essentially different from traditional approaches to NL modeling. To give the reader some insight into the basics of connectionist modeling, we provide an overview of two types of network architectures and their respective learning algorithms, (i) perceptron learning (Rosenblatt 1958) with the delta rule, and its popular backpropagation (BP) extension (Rumelhart et al. 1986), and (ii) self-organizing feature maps (SOFM) (Kohonen 1984). A low-level NLP domain, viz. hyphenation of English words, is taken as example application domain. Then, BP and SOFM occur in the description of a more complex connectionist natural language processing (CNLP) model of script processing and episodic memory, viz. DISCERN (Miikkulainen 1993). We conclude by addressing the question what connectionism has to offer to higher-level NL modeling.

2. Connectionist modeling

The central elements of connectionist models are interconnected, simple, neuron-like units grouped into networks. Long-term knowledge of a connectionist model is stored in the strengths (weights) of the connections between units. Weight settings are determined using appropriate automatic learning algorithms.

A description of the perceptron (Rosenblatt 1958) serves as reference point for a discussion of the most important principles of connectionist modeling. The perceptron is constructed from units which have a number of weighted input lines, connected to one output (Figure 1). Input signals can have the values 0 or 1. The output of a unit is determined by computing the weighted sum of its input signals. When this sum exceeds a certain threshold, the unit becomes active, i.e., has an output of 1. In all other cases, the output of the unit is 0.

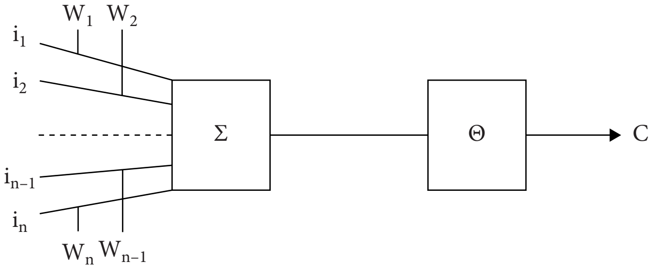

Figure 1. General architecture of a single-output perceptron. The input lines ($i_1 \ldots i_n$) with weights ($w_1 \ldots w_n$) are connected to an output unit in which the weighted input signals are summed (Σ); this weighted sum is then converted to the output signal o via the threshold function Θ

Table1. The nine windows of the word *ascendant* with their desired output, the weighted sum of inputs and the network output

window	desired output	weighted sum	network output
##asc	0	.028 − .446 + .245 + .189 + .170 = 0.186	0
#asce	0	.028 + .216 + .227 + .192 + .135 = 0.798	0
ascen	1	.162 + .241 + .243 + .227 + .163 = 1.036	1
scend	0	.134 + .214 + .221 + .191 + .113 = 0.873	0
cenda	0	.124 + .224 + .222 + .192 + .148 = 0.910	0
endan	1	.165 + .224 + .246 + .226 + .163 = 1.024	1
ndant	0	.148 + .229 + .245 + .191 + .161 = 0.974	0
dant$	0	.138 + .216 + .222 + .193 + .134 = 0.903	0
ant$$	0	.162 + .221 + .231 + .160 + .134 = 0.908	0

The perceptron of Figure 1 can be trained on word hyphenation. For that purpose, we present the perceptron with windows of 5 characters that 'shift' over the word to be hyphenated. For each window, the perceptron has to decide whether the middle letter of the window should be preceded by a hyphen or not. Table 1 lists the nine windows and the desired outputs of the word *ascendant* (*as-cen-dant*), and the perceptron's output for each window after training. Other information contained in Table 1 is discussed later in this section.

The input and the output signals of the Perceptron can have values 0 or 1: the output signal 1 represents the perceptron's decision that the position in the middle of the window is the position that may receive a hyphen. For representing an input window, 5 groups (the number of characters in the window) of 28 input lines (the number of possible letters per position: #abc … xyz$) are used, resulting in a network input of 140 lines in total. The characters # and $ represent left and right word boundary markers, respectively. To present a specific window input, each letter in the window is represented by setting the letter-specific input signal of the position-specific group to 1. For example, the presentation of the window *ascen* to the network leads to setting the second signal (representing *a*) in the first group to 1, and setting the twentieth signal (representing *s*) in the second group to 1, etc. All other signals are set to 0.

2.1 Learning within the perceptron

Each input line within the perceptron has a certain weight. Whether the perceptron is able to decide correctly on hyphenation positions depends completely on the setting of the weights of its 140 input lines. To train this particular single-output perceptron, 9580 English words were presented to the network, and a learning rule, the *delta-rule*, was used to set the weights during training. The essence of this learning rule is that when a perceptron incorrectly becomes activated after a certain input, the weights of the active input lines (that contributed to the error) are lowered. If the weights are decreased properly, the output signal will not exceed the threshold when presented with the same input again. Similarly, when the perceptron does not respond to an input it should respond to, weights of active input lines are increased. The weight change as performed by the delta-rule on the single output-perceptron used here, is captured in the following formula:

$$\delta w_i = \alpha * (O - o) * i_i$$

where δw_i is the weight change of input line i_i, α is a constant denoting the rate of weight change (also referred to as the learning rate), O is the desired output signal, o is the actual output signal, and i_i is the signal at input line number i. The higher the value of the learning rate α, the larger the weight changes are. Previous to training, all weights are randomly initialized (between −0.5 and +0.5). During training, words are presented to the perceptron as sequences of shifting windows. At each window presentation, the perceptron determines the output signal (if $(w_1 * i_1) + \ldots + (w_{140} * i_{140}) > 1.0$ the output is 1.0, else 0.0). The delta-rule is then invoked to update each weight. The resulting set of weights, after two learning cycles, is displayed in Table 2. Weights of input signals that have value 1 during the presentation of the window *ascend* are underlined.

Table 2. Weights of the 140 input lines (in 1/1000ths), divided in 5 position-specific groups of 28 specific letter inputs. Weights of active input lines during the presentation of *ascen* are underline

pos	#	A	B	C	D	E	F	G	H	I	J	K	L	M
1	28	162	125	124	138	165	113	84	107	127	113	123	137	109
2	−446	216	201	214	229	224	214	259	259	248	−4	273	237	241
3	283	245	288	243	246	221	277	234	210	218	27	220	251	233
4	−154	226	231	192	192	227	201	213	228	238	−369	−61	228	190
5	−140	148	134	170	113	135	147	165	156	177	−188	143	143	176

pos	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	$
1	148	121	97	71	106	134	124	152	124	99	136	142	148	42
2	221	247	237	−153	230	241	241	227	256	228	303	264	237	−333
3	222	225	266	257	229	227	231	220	212	243	184	240	219	11
4	191	240	178	236	203	189	193	241	−67	195	205	257	201	160
5	163	181	141	131	146	141	161	141	159	146	173	184	165	134

Using this weight table, the weighted sum of input signals for the presentation of *ascen* (the underlined weights in Table 2) can be computed: .162 + .241 + .243 + .227 + .163 = 1.036. The threshold of 1.0 is exceeded, and the output activation becomes 1 (i.e., the Perceptron indicates that a hyphen can be placed between *as* and *cendant*). For the complete processing of *ascendant*, see Table 1.

2.2 Backpropagation

After training, 85% of the training windows, and 80% of windows from words not presented during training, were assigned a correct hyphenation decision. This low score is hardly surprising, as the perceptron is only sensitive to the occurrence of specific letters in specific window positions, and not for combinations of letters. For example, it will not be able to learn that in English, hyphenation between *rr* is obligatory. The perceptron does not have any units that are able to be active at a cooccurrence of letters, and be silent when only one of the two letters is presented. This is because the perceptron directly maps input signals to an output signal using only a single layer of connections. The development of perceptrons with more than one single layer of connections between input and output, proved that these modeling limits could be surpassed. The use of intermediary layers introduced a new kind of knowledge representation. In our example, a unit in an intermediary (or *hidden layer*) could function as a recognizer of *rr* in the input. This intermediary information could be successfully used to calculate the correct output in a higher layer. It is also possible that the recognition of *rr* is performed by more than one 'hidden' unit. In this case, the representation is called *distributed*. No learning rule was found for such multi-layered perceptrons, until 1986, when a successful automatic learning algorithm, based on the delta-rule, was proposed (backpropagation (BP) learning: Rumelhart et al. 1986).

Applied to the example of English hyphenation, BP performs at a correct decision rate of over 95% on test material, which is indeed better than the perceptron. Although the learning capacity of BP networks is larger than that of perceptrons, processing is rather similar. As is the case with the perceptron, input and output are represented by vectors, but with real values on the interval [0,1] rather than just 0 and 1.

2.3 Self-organizing feature maps

The kind of learning that is displayed by the delta-rule and BP learning, where knowledge of the desired output is available during training, is called *supervised*. Alternatively, learning algorithms exist that base themselves only on input instances. An example of this kind of *unsupervised* learning can be found in implementations of self-organizing feature maps (SOFM) (Kohonen 1984).

The basis of the SOFM is a two-dimensional map of units. Each unit contains *n* weights (an *n-dimensional weight vector V*). The learning material consists of vectors *E*, also of dimension *n*. In our example of English word hyphenation, the learning material is in fact the same encoded material as was used with Perceptron learning (approximately 90,000 vectors of dimension 140).

Training a SOFM starts off with a random initialization of the weight vectors of the map. Then, the following training procedure is repeated, usually for a large number of cycles:

1. Randomly take an example vector (phoneme representation) from the training material (*E*).
2. Find on the map the unit of which the weight vector V_{win} minimally differs from the example vector *E*. Usually, Euclidean distance is taken as similarity metric.
3. Adapt V_{win} so that it becomes even more similar to *E*. This is done using the following learning rule: $V_{win-new} = V_{win} + (\alpha\,(E - V_{win}))$, where alpha is the learning rate. Usually, alpha is gradually decreased during training.
4. For the neighborhood units surrounding V_{win}, adapt the weight vector using the same learning rule, but with a smaller α (relative to the distance to the winning unit). The size of the neighborhood is large at the beginning of the training, and is made smaller during the training.

By applying this unsupervised learning procedure, the SOFM gradually represents a 2-dimensional map, in which weight vectors that are more similar to each other are physically located closer to each other than weight vectors that are less similar. In our example, this results in a map in which the windows mapping to a positive hyphenation decision (1) tend to cluster together (see Figure 2), although this information was not in any way present in the learning material. Apart from organizing the learning material in a possibly insightful manner, the SOFM can also be used to classify new vectors. Given such an input vector, the area in which a best matching unit is found determines the class of the new vector. In our example, we obtained a classification performance of about 85% on new material.

0	0	0	0	0	0	0	0	1
0	0	0	0	0	0	0	1	1
0	0	0	0	0	0	0	0	1
0	0	0	0	0	1	0	0	0
0	0	0	0	0	0	0	0	0
0	1	1	0	0	0	0	0	0
0	1	1	0	0	0	0	0	0
0	0	1	0	0	0	0	0	0
0	0	1	1	0	0	0	0	0
0	1	1	1	1	0	0	0	0

Figure 2. SOFM after self-organization of the word hyphenation window training set; 1/0 labels represent hyphenation decisions

3. Connectionist modeling and pragmatics

Successful CNLP models of low-level tasks (e.g., word hyphenation as in our example, and text-to-speech processing, Sejnowski & Rosenberg 1987) demonstrate the ability of connectionist learning techniques, such as BP, to capture the generalizations (implicit rules) within a simple domain by automatic learning and by representing domain knowledge in the form of connection weights. The question is whether this success can also be obtained with applying connectionist modeling to higher-level NLP domains, such as (sentence/story-) semantics or pragmatics. These domains generally imply the use of rich, structured knowledge representations for entities such as syntactic hierarchical structures of sentences and stories. As an example, we review a model of script processing and episodic memory, DISCERN (Miikkulainen 1993) in which rich structures are represented by simple, fixed length vectors, which are learned automatically. DISCERN is built entirely out of connectionist networks, which are linked in a modular structure. The model is able to read, process and store episodes, and report on stored episodes via rephrasing and question answering. The types of information that DISCERN manipulates are basically the same as those of more traditional approaches to script processing (e.g., Schank & Abelson 1977). This approach assumes that humans have knowledge of typical sequences of events (scripts, e.g., visiting a restaurant), for which some general variations exist (tracks, e.g., visiting a fancy restaurant, a fast-food restaurant, etc.), and which generally involve a fixed set of roles (customer, waiter, food, etc.), which have specific fillers at specific episodes. The main difference between DISCERN and the traditional approach is that DISCERN's knowledge representations are all distributed, and automatically learned.

DISCERN communicates with the outside world via a lexicon which is implemented in the form of two SOFMs. The first SOFM has automatically organized a lexicon of spelling words. The second SOFM organizes a lexicon of distributed semantic word representations, which are learned automatically, and which represent all contexts the word has been encountered in. This way, words that are used similarly have similar semantic representations. A lexical item is characterized by a best responding unit on the lexical SOFM, and a best responding unit on the semantic SOFM; a link exists between these units by means of automatically learned associative connections. This link is used during processing to retrieve the semantic representation of a spelling word, and vice versa.

The parsing component of DISCERN, which is able to read a story and generate a single, distributed story representation, consists of two connectionist networks. The first is trained to build a distributed representation of a sentence from sequences of words. Basically, a sentence representation contains in a compressed, distributed format the information on what the verb of the sentence is, who the subject is, where the action takes place, etc. The second parsing network is trained to form a distributed representation of the complete episode on the basis of the sequence of sentences. This episode representation contains distributed representations of the role-fillers of the episode (i.e., the script type and the track of the episode, and the specific role-fillers).

The memory component of DISCERN is organized in such a way that it classifies a new episode in three steps. First, a small SOFM determines the script of the episode. A second SOFM determines the track of the episode, and a third SOFM stores all the unique information about the specific role-fillers. During story generation (or paraphrasing), the memory storage process is reversed, and the full story is generated by the inverse of the parsing component. In this generation process, information can be inferred that was not explicitly mentioned in the specific episode story, but had occurred earlier during other episodes and was learned as being typical for that episode. The question-answering component, finally, exploits the flexibility of the memory-SOFMs: it transforms a question about an episode into a distributed episode representation with the subject of the question represented as missing information. Although the representation with the missing information does not match any stored episode exactly, in almost every case the specific episode that the question addressed is the best matching unit found on the third memory SOFM.

As a whole, the functioning of the model demonstrates the feasibility of CNLP. DISCERN successfully makes use of the fact that connectionist processing of distributed knowledge is robust, and fairly resistant to noise, missing or 'ungrammatical' information (Miikkulainen 1993). However, DISCERN has some deficiencies. At some points, knowledge is hand-wired into the system, and not automatically learned. Moreover, the problem of how to represent structured knowledge in connectionist networks is only partly addressed in this model, as the data being used consists of very simple and short sentences. The question remains whether the model could be scaled up to processing more scripts and more complex sentences.

4. Discussion

Connectionist modeling offers the capability to learn automatically from examples, and generalize from these examples. This approach is in contrast with the traditional approach to explicit linguistic knowledge acquisition, which is generally lengthy. Once data is available, this *knowledge acquisition bottleneck* for acquiring symbolic rule systems can be surpassed. A historical critique of connectionist theory is that symbolic processing is an essential property of NLP, whereas the nonsymbolic nature of distributed knowledge representation is not very well suited for representing structured symbolic knowledge (Fodor & Pylyshyn 1988; Hinton 1990). Furthermore, automatically formed distributed representations are rather opaque, in the sense that the functioning of a PDP system cannot easily be understood from the architecture and weight setting of the trained system.

Most of the notions that connectionism has brought into the field of NLP are not intrinsically novel, but many have provided the field with new possible solutions for old problems (for an excellent overview, see Reilley & Sharkey 1992). Within higher-level NLP domains (e.g., sentence or story syntax, semantics and pragmatics), symbolic, structured knowledge representation seems essential. Recent connectionist research focusing on CNLP has taken up the challenge by presenting connectionist alternatives to representing and storing structured knowledge. Elman (1990) shows that so-called simple recurrent networks (SRN) can learn to represent sequences, e.g., to predict successive elements of a sequence, in a distributed way. Servan-Schreiber et al. (1991) present an example of an SRN which is able to learn sequences, generated by a finite state grammar, with a reasonable amount of structural embedding. In the example of DISCERN, networks were used for learning representations of output sequences used in parsing processes, and representations of input sequences used in generation processes.

The scalability of these models to large amounts of knowledge (as one would assume when dealing with modeling world knowledge), is not without problems. Minsky & Papert (1988) assert that scalability is still a major bottleneck for connectionist modeling. Without resorting to symbolic, data-base memory modules (as is done in several hybrid connectionist/symbolic models of script processing, e.g., Lee et al. 1990; Mannes & Doane 1991), the toolkit is limited. Only SOFMs (Kohonen 1984) at present really appear to be suited for modeling large-scale storage.

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Consciousness and language

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During most of the twentieth century the possibility that there is an important relation between consciousness and language was largely ignored. Aside from the possibility that there is in fact no relationship worth considering, the reasons for this neglect include the dominance within psychology of behaviorism, which rejected consciousness as having no scientific value; the parallel influence of Freudian psychology, which found greater interest in the subconscious than in the conscious; and within linguistics a bias against 'psychologizing'. But consciousness has now become a more respectable topic within at least some schools of psychology, and its relevance to language has begun to receive some attention.

Consciousness has been notoriously difficult to pin down because it has no directly observable physical substance, although in the future brain imaging may change that picture to some degree. The study of consciousness immediately raises the usual problems associated with introspection. If mainstream psychology has tried to avoid introspection wherever possible, linguists have made liberal use of it in various ways. To conclude, for example, that *boys* is the plural of *boy* is based on introspective knowledge of how one uses the English language. The decision as to whether some arbitrary sequence of words is 'grammatical' or not is wholly a matter of introspection. To quote William James, "*introspection is difficult and fallible; [but] the difficulty is simply that of all observation of whatever kind*… The only safeguard is in the final consensus of our farther knowledge about the thing in question, later views correcting earlier ones, until at last the harmony of a consistent system is reached" (James 1890, 1:191–92; cf. Chafe 1994: 14).

Within linguistics two different positions regarding the relation between consciousness and language have developed, as set forth especially in Jackendoff (1987, 1996) and Chafe (1974, 1980b, 1994, 1996a, 1996b). Crucial to both these authors is the relation between language and thought. Both agree that thought cannot be equated with conscious experience in the form of inner language, nonverbal imagery, or some combination of the two. Jackendoff concludes that "thought is totally unconscious", but sees it nevertheless as the driving force behind language. He suggests three ways in which language enhances the power of thought. First, language makes possible the communication among humans of a broad range of knowledge: "As a result of having language, vastly more of our knowledge is collective and cumulative than that of nonlinguistic organisms". Second, language makes thought available to attention, thus enhancing the way thinking is experienced. Particularly significant is the fact that through language it becomes possible to pay attention to the abstract and relational elements of thought, so that people can work with them in ways that would otherwise be impossible. Third, language also brings to attention what Jackendoff calls 'valuations' of thought elements, such as judgments regarding their truth or falsity, allowing those valuations to be worked with as well.

While Jackendoff sees thought itself as operating outside of consciousness, with conscious phenomena like language and imagery providing indirect access to it and bringing aspects of it to attention, Chafe sees the contents of consciousness as playing a major role in the shaping of language. The disagreement appears to stem from differing views regarding the kinds of experiences of which people can be conscious. Jackendoff limits the contents of consciousness to perceptual and affective phenomena, whereas Chafe extends them to more abstract aspects of experience, quoting William James again to the effect that "the definite images of traditional psychology form but the very smallest part of our minds as they actually live" (James 1890, 1:255; cf. Chafe 1996b: 183).

The following discussion is based on the view that consciousness plays a pervasive role in the shaping of language. Although both the content and the flow of consciousness may be in part unconsciously determined, and although the use of language may depend considerably on unconscious mental structures and processes, at the same time consciousness will be assumed here to be the place where remembering, imagining, evaluating, and speaking come together to produce both thought and language.

1. Properties of consciousness

If one observes language in action and remains alert to introspections which are neither especially difficult nor controversial, it seems possible to identify several properties of consciousness that affect the shape of language, distinguishing between constant properties that are shared by all conscious experiences and other properties that vary from one experience to another.

Among the constant properties of consciousness that are relevant to language are the presence of both a focal and a peripheral consciousness, analogous to foveal and peripheral vision. Focal consciousness, furthermore, does not stand still, but is constantly shifting from one focus to another. This pattern of a constantly shifting focus against a peripheral background seems always to be oriented with respect to a point of view that functions in the interests of the conscious organism. Finally, consciousness seems always to need a background orientation in terms of the space, time, society, and ongoing activity within which the conscious self is located. Among the variable properties of consciousness are at least the following five. First, a conscious experience may originate in a mixture of sources, including perceptions, actions, and evaluations, and sometimes also introspections. The term 'evaluations' is meant to cover whatever emotions, feelings, and attitudes are associated with perceptual experiences. These several sources of conscious experience are not mutually exclusive, and it may well be that an evaluative component is always present (cf. Damasio 1994 for the importance of emotions to what might be thought of as dispassionate 'reasoning'). A second variable property of consciousness is the choice between whether an experience is derived from the immediate environment or is displaced, a product of remembering or imagining. A third variable property involves the experiencer's judgment of whether the content of consciousness is factual or fictional. Even if such a judgment need not accord with external reality, language shows that people do assign degrees of factuality to their conscious thoughts. Fourth, conscious experiences vary along a dimension of 'interestingness': some experiences are interesting or exciting, others comforting or boring. A fifth variable property involves the verbality or nonverbality of the experience: whether or not it consists of inner language.

The following are a few of the ways in which language is shaped by the properties of consciousness just listed. It is important to keep in mind that language is also shaped by the different ways it is used, whether in silent thinking, overt speaking, or writing. Speaking and writing differ in obvious ways. Speaking is evanescent, while writing is more or less lasting. Speaking is rapid, whereas writing is slow in production and can be fast in reception. Speaking is irrevocable, while writing may be painstakingly worked over. Speaking exploits a rich prosody which is much diminished in the ordinary conventions of writing. Speaking comes naturally, while writing must be deliberately learned. Finally, prototypical speaking is situated, in the sense that the producer and receiver share a time and space and the ability to interact. There are, of course, many varieties of speaking and many varieties of writing, each an adaptation to the circumstances of its use. The language of ordinary spoken conversation, however, enjoys a special status as the most natural use of all, and it can thus serve as a baseline for studying uses that diverge from it.

2. Foci of consciousness

The fact that consciousness has a limited, constantly shifting focus is evident from the observation that speech is produced in a series of brief, prosodically definable spurts, typically between one and two seconds long, which have been called *tone units, intonation units,* and the like. The boundaries of these prosodic units can be recognized from a variety of criteria, including their typical separation by temporal interruptions (either significant pauses or slight breaks in timing), often an acceleration at the beginning and/or a deceleration at the end, a shift to a new pitch baseline, a distinctive final intonation contour, and sometimes a final change in voice quality such as creaky voice or devoicing. Intonation units are, of course, most clearly marked when most or all of these boundary criteria are present, but it has been useful to accept as intonation units also those which diverge from such prototypical cases, so long as at least some prosodic evidence for their boundaries is present.

The following example from Chafe (1994: 66–67) illustrates something of the nature of intonation units. Two farmers, identified as A and B, were talking about spraying their crops.[1]

(1) a. (A) … Cause I had a … a thíck pátch of bárley there,
b. (B) … Mhm,
c. (A) .. about the sìze of the .. kìtchen and líving room,
d. (A) .. and then,
e. (A) … when I got dóne,
f. (A) … I had a little bit léft,
g. (A) .. so I tùrned aróund,
h. (A) and I wènt and spràyed it twíce.
i. (A) .. And ìt's just as yèllow as … can bé.

It is intuitively satisfying and has productive consequences if intonation units are viewed as the linguistic expressions of information that is, at first, in the focal consciousness of the speaker and is intended, through the utterance of the intonation unit, to become active in some form in the consciousness of the listener. Not all intonation units express substantive ideas (B's one contribution to the above sequence was reactive only), but substantive units in English conversation show a modal length of four words, a fact that suggests an important constraint on how much information can be fully active in the mind at one time.

Intonation units often take the syntactic form of clauses, as exemplified by two-thirds of the intonation units in (1). It is not unusual, however, for an intonation unit to consist of less than a clause, as with the noun phrase in (1c) (*about the size of the kitchen and living room*), or nothing more than connectives, as with (1d) (*and then*). The function of a clause is to verbalize the idea of an event (*so I turned around*) or a state (*and it's just as yellow as can be*). Usually each intonation unit verbalizes the idea of a different event or state from the preceding intonation unit, a fact which suggests that ideas of events and states tend to be highly transient in active consciousness. Most events and states incorporate one or more referents-ideas of people, objects, or abstractions-that function as participants in them. Unlike the event or state ideas themselves, many of these referent ideas do persist, remaining active through a series of intonation units, as was true here of the idea of the speaker expressed with the word *I*.

1. Acute and grave accent marks show primary and secondary accents respectively. Sequences of two and three dots show very brief and normal-length pauses. The period at the end of an intonation unit shows a sentence-final falling pitch contour, while the comma covers any other terminal contour.

3. Activation cost

As one focus of consciousness replaces another, the idea of some referent, event, or state may either *remain* active or *become* active. This process underlies what is usually thought of as the distinction between given and new information, or *activation cost* (Chafe 1994: 71–81). Language works best when the expression of activation cost is listener-oriented, in which case a *given* idea is one that is judged to be already active for the listener, while a *new* idea is one that is judged to have been previously inactive for the listener. It has been useful to recognize a third category of *accessible* information in order to characterize an idea that is judged to have been previously semiactive for the listener.

These three activation costs-given, accessible, and new-provide an example of how consciousness can affect the shape of language. Given information is typically verbalized with phonetically attenuated material, as when a given referent is expressed with a weakly accented pronoun like the *I* throughout (1) or the *it* in (1h) and (1i). New information is verbalized with a primary accent and typically with a full noun phrase, as with *a thick patch of barley* in (1a) and *the kitchen and living room* in (1c). Accessible information is not as consistently recognizable through the form of its expression, but hypothesizing its special status has indirect benefits, as discussed in part below.

The value of recognizing intonation units and the varying activation cost of ideas can be illustrated with the hypothesis that, in ordinary conversation, a single intonation unit can express no more than one new idea. This hypothesis goes back at least to Givón's suggestion that "there exists a strategy of information processing in language such that the amount of new information per a certain unit of *message-transaction* is restricted in a fashion-say 'one unit per proposition' (Givón 1975: 202). Exploring the validity of the hypothesis requires a careful specification of what is meant by the terms *one, new,* and *idea*. I have already sketched a way of understanding *new*, but it is necessary also to consider what constitutes *one idea*.

This question is fruitful because it forces a clearer understanding of *lexicalization*, the historical process by which a combination of words comes to be established as a fixed way of verbalizing an institutionalized idea. Two processes are involved in lexicalization: the process by which the idea of an event, state, or referent becomes culturally familiar, and the process by which a particular phrase becomes established as a conventional way of verbalizing an idea of that kind. An example from (1) is the phrase *living room* in (1c), referring to a culturally familiar kind of room. The relevance of such an example to the one new idea hypothesis is the removal of any necessity to consider the words *living* and *room* to be expressions of separate new ideas. Andrew Pawley & Frances Syder have emphasized the extent to which nativelike fluency in a language depends on a speaker's familiarity with a huge store of such lexicalized phrases (e.g. Pawley & Syder 1983).

Not only does the one new idea hypothesis shed light on lexicalization, it also leads to a recognition that not all linguistic elements exact an activation cost. Those that do can be called expressions of *ideas*, in the sense of mental representations of perceived, remembered, or imagined events, states, and referents. Ideas, thus defined, are expressed by content words and pronouns. Other elements of language-function words and affixes-express types of content that lie outside the domain of activation cost, content that is neither given, accessible, nor new.

The manner in which the one new idea hypothesis sheds light on several of these factors can be illustrated with (1h):

(1) h. and I wènt and spràyed it twíce.

The first word, *and*, links this event temporally to the preceding event of turning around. Such linking elements fail to exact an activation cost. The pronouns *I* and *it* express the given ideas of the speaker and the thick patch of barley. The phrase *went and* expresses a subtle periphrastic modification of the spraying event, indicating that it was something the speaker did without further thought. It too fails to exact an activation cost. The idea of *spraying* was accessible from the preceding context; the topic from which this segment was excerpted had to do with spraying parts of the speaker's field. Thus, the word *twice* was the only expression in (1h) of a new idea, a fact which determined its strong accent and its placement at the end of the clause.

The one new idea constraint is so pervasively responsible for shaping ordinary spoken language that it is worth searching for explanations for apparent exceptions. When potential counterevidence is found, there is value in searching for properties that consistently differentiate such evidence from that which fits the hypothesis more directly. Often a search of this kind leads to the recognition of previously unsuspected regularities, or to profitable extensions and modifications of the hypothesis itself.

4. Discourse topics

Having recognized intonation units as the expressions of individual foci of consciousness, each with a strictly limited capacity, one also needs to examine how language is shaped by larger aggregates of *semiactive* information. These larger coherences can be labeled *discourse topics*. A topic in this sense is another kind of *idea*, a coherent chunk of substantive information that organizes both thought and language. Too comprehensive to be active in consciousness all at once, a semiactive topic must be scanned by a more restricted focus of active consciousness. When the scanning is verbalized, the result is an episodic or paragraph-like unit of language.

The fact that speakers so often begin a topic by providing a setting-an orientation in terms of space, time, participants, and background activity-suggests that information of this kind is required by a well-ordered consciousness. The following setting was provided at the beginning of a conversational narrative (Chafe 1994: 129):

(2) a. … The làst time I was thére,
b. .. I was only there ónce,
c. .. Tuo .. Tuólomne ónce.
d. … A=nd uh=
e. … a búnch of us were híking.

With this statement the speaker initiated a new topic during which she would go on to describe a series of events that were witnessed by 'a bunch of us' during the hike. The sequence in (2) oriented the listener's consciousness to the place and time of this topic, to major participants in it, and to their background activity (the hiking). The fact that speakers typically introduce a topic in this way suggests a tacit awareness that consciousness has a need for this kind of information.

One can speculate on the role of sentences in this picture. Although sentences have been treated as the most basic of linguistic units, they do not always emerge from ordinary speaking with compelling clarity. What, for example, can one make of (2a–c) in terms of sentence structure? And yet this sequence is an unremarkable example of spoken language. Sequences of natural intonation units do not always combine to form structures with the sentential properties traditionally assigned to constructed data.

Ordinary speech often does contain well-formed sentences nevertheless. They evidently function to bring together aggregates of information that are too large to be accommodated within a single focus of consciousness, but are intermediate in comprehensiveness between a single focus and a discourse topic. Whereas both intonation units and discourse topics remain relatively stable in content across different tellings of the same experience by the same individual, sentences do not. The information brought together in a sentence appears not to represent a cognitively stable unit of perception, storage, or remembering. Rather, sentence boundaries-whether syntactic, prosodic, or both-appear when the speaker judges a coherent center of interest to have been verbalized at that point. There are various grounds for making such a judgment, and those grounds are subject to variation in repeated verbalizations of the same material. Sentences, in short, appear to result from on-line, fleeting decisions with regard to coherence at this intermediate level. While foci of consciousness and more comprehensive topics are constrained by innate cognitive mechanisms, that does not seem to be the case with sentences.

Example (1) above illustrates other properties of consciousness among those listed earlier, showing how conscious experience can arise from perceptions (*and it's just as yellow as can be*) and from actions (*so I turned around*). The fact that the consciousness responsible for (1) has a point of view (the speaker's) is evident from the several first person references and their use as grammatical subjects. The judgment that this experience was interesting, and thus worth contributing to the conversation, affected the language in several ways, among them the evaluative phrase *as yellow as can be*, but especially the speaker's effective use of prosody (pitch, volume, duration, and voice quality), features of language that are not well shown in the transcription.

5. Immediacy and displacement

The above discussion sketched some of the ways in which consciousness affects the prosody of ordinary spoken language, the manner in which referents are verbalized (for example with pronouns or full noun phrases), and the establishment of discourse topics. Certain kinds of writing shed light on patterns that are not as obvious in ordinary speaking. Among the variable properties of consciousness listed above was the distinction between experiences derived from the immediate environment of the experiencer and those that are *displaced*: products of remembering and/or imagining. Consciousness is sometimes focused on the immediate environment, but there are many other occasions when an experience is remembered or imagined. On this basis it is possible to say that both consciousness and language are sometimes in the immediate, sometimes in the displaced mode.

Of significance for language is the fact that immediate and displaced experiences are qualitatively different. For one thing, immediate experience is continuous, in the sense that people's lives are experienced as proceeding continuously through time, whereas displaced experience is island-like. People remember or imagine isolated incidents, detached from their preceding and following contexts. It is also the case that immediate experience is richly detailed, in the sense that one feels one has access to everything that is 'out there', even though one actually focuses on no more than one small part of it at a time. Displaced experience, in contrast, is impoverished: people remember only attenuated images, evaluations of them, and related language.

In the displaced mode there are actually two distinguishable consciousnesses that contribute to the experience, one proximal and the other distal. In spoken language the proximal consciousness is that of the speaker at the time and place of the speaking. This consciousness is responsible for the production of the language, and on that basis it can be called the *representing* consciousness. But its content is also what is expressed by the language, and for that reason it can also be called the *represented* consciousness, as sketched in Figure 1 (cf. the fuller diagram in Chafe 1994: 199).

remembering
DISTAL CONSCIOUSNESS ⟶ PROXIMAL CONSCIOUSNESS
represented — representing

Figure 1. Consciousness in the Displaced Mode

In the displaced mode the content of the represented consciousness is derived through remembering (or in other cases imagining) from a different, distal consciousness. That distal consciousness may in its own time have been immediate, but what is represented by the language is not the distal consciousness itself, but only the speaker's remembering of it. The distal consciousness may once have had the qualities of continuity and rich detail associated with immediacy, but the process of remembering produces something island-like, with attenuated detail.

The value of distinguishing between a representing and a represented consciousness would not be apparent if it were not for certain ways in which these two functions have been manipulated by writers. As noted earlier, writing is usually desituated, which is to say that the producer and receiver of the language are spatially and temporally separated and lack the ability to interact directly. This desituatedness provides an environment in which writers find it possible to do things with language that conversationalists ordinarily do not do, thus illuminating aspects of both language and consciousness that might not otherwise be noticed. For example, some writers exploit a difference between adverbs of space and time like *here, there, now*, and *then* on the one hand and expressions of tense on the other hand, by separating the represented from the representing consciousness as suggested in Figure 2 (cf. Chafe 1994: 227).

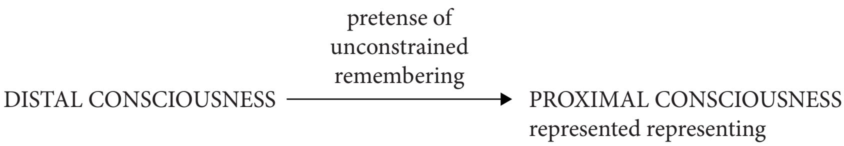

Figure 2. Displaced Immediacy

The resulting language conveys an experience displaced from the environment of the representing consciousness, but the represented consciousness is fictionally endowed with properties of immediacy, unlike the ordinary represented consciousness of Figure 1.

One of those properties is the richness of detail that is characteristic of an immediate rather than displaced experience. Chafe (1994: 251) illustrates this richness with various passages from fiction, including the following from Ernest Hemingway's short story "Big Two-Hearted River" (Hemingway 1987: 167):

(3) He started a fire with some chunks of pine he got with the ax from a stump. Over the fire he stuck a wire grill, pushing the four legs down into the ground with his boot. Nick put the frying pan on the grill over the flames. He was hungrier. The beans and spaghetti warmed. Nick stirred them and mixed them together. They began to bubble, making little bubbles that rose with difficulty to the surface. There was a good smell.

These are details of a sort that would be available to an immediate consciousness, but not ordinarily to one that was remembering.

From the point of view of ordinary conversational language there is an incongruity between the immediacy expressed by the detail in (3) and the use of past tense throughout this passage. The function of past tense can usefully be described in terms of the relation between a proximal and a distal consciousness: past tense 'means' that the time of the distal consciousness preceded the time of the proximal consciousness. That incongruity, however, may be subtle enough to escape the attention of a casual observer. Readers of fiction are used to it, and would be unlikely to notice what is odd about (3) from a spoken language point of view. A more obvious incongruity, simply because it appears in obvious elements of linguistic form, is the use of temporal adverbs like *now* or *today* with the past tense (Hemingway 1987: 180):

(4) Nick did not want to go in there now. … He did not want to go down the stream any further today.

Examples like (4) point to an interesting difference between the deixis of tense, on the one hand, and of spatiotemporal adverbs on the other. Briefly put, the deictic center for tense is the *representing* consciousness, whereas the deictic center for spatiotemporal adverbs is the *represented* consciousness. Tense relates the time of an experience to the time of the representing consciousness. The past and future tenses signal that the time of the experience was prior to or is anticipated to follow the time of the representing consciousness, while the present tense signals that the time of the experience coincides with the time of the representing consciousness. Quite differently, spatiotemporal adverbs locate an experience in space or time with reference to the represented consciousness. *Here, now,* and *today* signal coincidence with the space and time of the represented consciousness, whereas *there, then, yesterday*, and *tomorrow* point to a space and time different from that of the represented consciousness. Because in ordinary speaking the represented and representing consciousnesses are almost always congruent, there is a natural tendency to regard *now*, for example, as symbiotic with the present tense. But when the represented and representing consciousnesses are separated, as they are in (4), it is entirely natural for *now* and *today* and the past tense to occur together. This differing behavior of tense and adverbs can be satisfactorily understood only if one recognizes that consciousness may be either immediate or displaced, and only if one takes account of the distinct qualities of these two modes.

6. Conclusion

What might be called the strong view of the relation between language and consciousness holds that consciousness and its properties must be brought fully into the picture if a more complete understanding of language and the mind is to be achieved. Consciousness, according to this view, is relevant to such obvious linguistic phenomena as pronouns, adverbs, conjunctions, tense, sentences, paragraphs, and prosody. There is a need for careful studies based on observations of natural language that will investigate such consciousness-related phenomena as the one new idea constraint, the establishment and development of discourse topics, and the different natures of immediacy and displacement.

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Developmental psychology

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1. Historical overview

The modern field of developmental psychology is a descendant of the 18th and 19th century natural history movement. Nineteenth century observers like Darwin, who studied his son's development in comparison with other species, and many diarists who observed their own children, created a body of descriptive literature which was part of the same movement of close observation that affected ethology.

The scientific concerns in these studies grew largely out of the impact of evolutionary theory, leading to the proposal that children recapitulated evolution, a notion promoted by anatomical evidence such as residual fetal features and early reflexes — ontogeny recapitulates phylogeny. This notion fitted the evolutionary and normative model, which was used everywhere in characterizing the development of animals from simpler to more complex forms, the development of societies towards industrialization, and the development of children from infants to adults. Children were viewed as in a state of preparation to become societally constrained adults, and the elderly were seen as in decline from the optimum. The bulk of developmental psychology was oriented to telic change, to the view that the reduction of error and the approach to adult knowledge and adult behavior should be the topic of analysis. Developmentally advanced and developmentally retarded were value terms in such a view. An important component of the developmental perspective was the view that developmental processes were orderly, and at least in part universal and predictable.

A second major thread which affected studies of development was practical concern with the problems afflicting children and the aged. In the industrial era, social dislocations put a large number of children and elderly in need of public care, creating a desire for studies of effective intervention. Care of children with sensory deficits and apparent mental retardation raised a desire for interventions aimed at approximating what was seen as a normal course and rate of development. Clinical studies implied presuppositions about what was normal. Many centers for the study of development were called institutes of child welfare because of these practical concerns, and journals and magazines popularized child development studies. The mental measurement movement also originated in practical goals — selection for armies and selection for school programs. Its focus on objectivity and repeatability in procedures of assessment strongly affected certain centers of research.

A related factor affecting studies of development was the invention of a form of psychology based on the physical and biological experimental model. Developmental psychology grew up in the environment of late 19th century social science, which sought to apply scientific methods to human behavior. These new studies combined a hypothesis-testing approach allowing disconfirmation of theories with a belief that it was possible to find precise measures which would validly assess the theoretical variable at issue, and to create reliable observational methods allowing for replicability of findings over time and with different investigators. These criteria were the foundation of scientific psychology.

The history and focus of developmental psychology has not been identical everywhere but was colored by local ideology. In the second quarter of the twentieth century, for example, in the Soviet Union and in the United States perspectives which focused on external behavior rather than mental processes were dominant; in western Europe more interpretive perspectives were preferred.

Since beliefs about the nature of children and the aged, and about their role in society, vary culturally, the dominance of research funding, training, and publications by Europeans and Americans has affected the focus of research in the field.

2. The concept of development

The basic assumption of developmental psychology is that the mind and emotional processes develop in an orderly way, as the body does, throughout the life span. Developmental psychologists are interested in structures, knowledge, feelings, skills, procedures, and behavior, in their origin, development, and change. Developmental theories have models of developmental change, assumptions about what causes change, and assumptions about patterns of change.

3. Major research issues

3.1 Causes of development

It has been obvious that some features of development are biologically predictable, but exactly which are based on fetal age and relatively impervious to external influence (e.g. development of reflexes), which are canalized by environmental stimulation (e.g. visual acuity), and the extent of environmental effect, have all been hotly debated, even swinging with the political climate because of implications for social policy (Scarr 1992; Lewontin 1994). An example of this dispute is gender identity and whether there are cognitive and social developmental differences between males and females which are endogenous. It is assumed by most students of language development that many aspects of the capacity to learn language are biologically pre-established by evolution, but there is considerable dispute about how much, given the diversity of languages. The problem is to discover the origin and developmental course of each of the primitives supposed to be universal.

3.2 Continuities and discontinuities

Humans share 98% of their DNA with chimpanzees, but the development of grammatically structured language and of elaborate cultural transmission marks a phylogenetic discontinuity from other species. Those who see ontogenetic change as qualitative and discontinuous refer to stages of development in which a widespread, simultaneous transition occurs fairly quickly in several domains of behavior, suggesting underlying reorganization (Piaget 1977). Examples of such changes can be seen in phonological development (Smith 1973). Related questions are the notion of a critical period, that is, a transition point beyond which some change is impossible, and the continuity of individual differences through the life span.

3.3 Critical periods

The notion of a critical period is that there are crucial conditions for the development of a capacity, and that if these conditions do not obtain by a certain stage, development can never be normal or complete. The infant critical periods are well established for genitalia development and for visual acuity, but critical periods have been variously identified with respect to language, drawing on data from brain injury, social isolation, late learning, or lateralization experiments (Bever 1971; Curtiss 1989; Newport 1991; Lenneberg 1967).

3.4 Individual and group differences

The study of differences is of interest descriptively, but it can also be a route to the discovery of causes of development. For example, many differences have been found between boys and girls, including differences in verbal activities in groups (Goodwin 1990), but a debate continues as to the biological and social contributions to these contrasts. Cross-cultural studies provide one test of what is causally social (Whiting & Whiting 1975; Schieffelin & Ochs 1986).

4. Points of view on development

4.1 Biological-maturational perspectives

In some theories, there is assumed to be a biological clock which dominates developmental change. Biologically programmed development typically shows a time difference based on gestational age, not birth age. For example, smiling develops later in premature infants than full-term infants, in terms of post-natal age, so it could be said to follow gestational age. In such views, learning plays no role in transitions between stages, but triggering may occur (Braine 1994). Current evolutionary and biological psychology has downplayed both modularity in mental processes and hard-wiring of any complex behavior in humans, because of the evidence for increasing flexibility in behavior and brain functioning with phylogeny.

4.2 Triggering theories

Some theorists make space for limited environmental impact by allowing that environmental events must trigger the biologically programmed changes. Oral language could not develop, everyone agrees, unless it is heard. In terms of biologically-timed developments, 'canalization' refers to environmental stimuli that must be present, such as sharp boundaries in retinal stimuli in infancy for visual acuity development. In the study of language development, nativists propose that speech in the child's environment serves as a trigger to the development of biologically programmed capacities.

4.3 Constructivism

Constructivists believe that people play an active role in interpreting the environment and that there is an interaction between biology and environment in development. The best known constructivist was Jean Piaget, whose views of the interaction between the child and the environment (assimilation, accommodation, and the reorganizations stimulated by discrepancies in different domains) have had a strong impact, particularly on the study of cognitive development. Some theorists who take a constructivist/interactionist view of development (e.g. Vygotsky 1978, 1987; Wertsch 1985) include cultural and interactional differences in what the child must assimilate as part of the stimulating world. They would thus predict some developmental differences due to cultural contrast, rather than universal stages.

4.4 Socialization and learning

In the study of social behavior, points of view derived from learning theories or combinations of learning theories with neo-Freudian views influenced many studies. From this perspective, 'socialization' involves the impact of reward, punishment, and modeling, or of identification with loved and powerful others. Socialization refers to the factors that bring the person into the group of peers or of older models and tutors, and get the new member of the community to behave like others.

5. Methods of study

The preferred methods in the early stages of work on human development were self-reports, with the attendant problems of accuracy of memory, and family diaries, a method used by Darwin, and still used in language development studies (Leopold 1939–49; Fantini 1985).

With the development of scientific psychology came a concern with precision of measurement and data collection, and methods of analysis which could be described and repeated for confirmation. Systematic observation of children in their normal environments was a method used in American (Barker & Wright 1955) and European (Dunn 1993) family and community settings, and in studies in other cultural environments (Whiting & Whiting 1975). The problem with observational methods used alone was that they did not reveal why choices were made. The clinical interview which follows up on the subjects' answers to explore their reasoning was elaborated by Piaget to question children individually about common experiences or about specific procedures done systematically for each child. More frequent in psychological research are experiments and controlled eliciting (Andersen 1990; Berman & Slobin 1994). Brunswik (1947) proposed that experimenters aim at ecological validity, making experiments as much like normal familiar activities and settings as possible to permit generalization. Such a proposal implies a need for research on or a theory of normal interaction as a methodological basis for recognizing the demand properties of settings.

5.1 Longitudinal vs. cross-sectional studies

Studies of development should ideally be longitudinal, that is, conducted on the same subjects over a period of time, but the practical problems both for the commitment of the researcher's time and for reaching subjects over time have led to short longitudinal studies starting at different ages, and cross-sectional studies of people at various ages. Generalizations from cross-sectional studies do not provide evidence on different developmental trajectories, but assume similarities in development for everyone.

5.2 Comparative and ethnographic research

Ethnographers have studied development in other societies, but their focus has typically not been on longitudinal change through the life span, but on contrasts in the contexts of socialization (Schieffelin & Ochs 1986). There are also cross-cultural comparisons in which the same experimental or observational techniques have been used in other cultural settings for comparative purposes (Saxe 1991; Whiting & Whiting 1975).

5.3 Individual differences

Comparisons of individuals longitudinally allow the study of issues of continuity across time and of causation. Cross-sectional studies involving several measures allow correlations (Dimitracopoulou 1990), or with time-lags on the measures in a longitudinal design, some causal attributions (Camaioni & Longobardi 1994). A time lag-study is one that shows that individuals measuring high on variable A at time X are predictably high on variable B at time X+1, whereas the reverse is not true: B will not predict A. This technique can remove the ambiguity of correlational results.

5.4 Sampling and generalization

In the early stages of research on developmental issues, when it is assumed that the problem is discovering parameters and basic patterns of development, there is typically small concern with systematic sampling, which allows generalizing from a few cases, hence the success of diary descriptions in the early years of developmental research. Findings of gender, social class, and cultural differences and of setting effects on behavior have raised issues of systematic sampling of the population of subjects or of the settings to which generalization is proposed.

6. Pragmatic perspectives on development

Throughout the life span, the participants, settings, and activities involving speech all change, as does the manner in which participants interpret and use them, since interpretation is affected by social and cognitive development. Not only do pragmatic studies depend on sensitivity to these changes, but developmental psychologists' design of ecologically valid experiments or sampling of observational settings could be enriched by pragmatic research findings. An example would be taking into consideration the impact of adult experimenters as participants on produced speech of children, or the impact of familiar settings as contrasted with laboratory settings.

The fundamental pragmatic unit is the activity and its phases (Goodwin 1990; Gee & Savasir 1985). Sometimes activities are labeled as speech events with conventionalized episodes, as in ceremonies and games, but not all activities are recognizable by name, some just by regularity of pattern. These activities change in the life span, both in complexity of structure and in the degree of separate elaboration of purely verbal aspects, such as complex disputes or reports. In contrast, early child language is typically closely integrated with non-verbal activities, with regularities limited to local cross-turn discourse.

The earliest features of pragmatic organization appear at what Schiffrin (1987) has called the action level, involving adjacency pair routines, then pairs which look like speech acts, and then longer exchanges, such as disputes and play activities (McTear 1985). The organization of global episodes occurs later than the local structure. Identification of ideational units such as topics, and the marking of ideational relations between propositions in clauses, for instance in narratives, occurs later than action marking.

The indexing of social meaning by the choice of language for addressee types (Fantini 1985), register for role types (as in baby-talk register) (Andersen 1990), and speech markers of mitigation and aggravation according to social properties such as object ownership appear by the age of three (Ervin-Tripp, Guo & Lampert 1990) and change in complexity and variety with age.

7. Some relations of pragmatics to developmental issues

7.1 Sources of language development

Developmental psychologists can use variables identified in pragmatic research to study causal features in language development. For example, it would be possible to separate the effects of adult, sibling and peer talk on aspects of language development. Most of the focus of research has been on parental influence. Using a cross-lagged longitudinal design, Camaioni & Longobardi (1994) showed that if mothers interrupted toddlers' activities a lot, by overlapping, ignoring initiatives or changing the topic, they significantly delayed the development of vocabulary and fluency 4 months later. If mothers supported children's initiatives by repeating, expanding, reformulating, paraphrasing, praising, referring to shared knowledge or replying by activity or game routines, their children were linguistically precocious. Thus the second turn in local child-initiated discourse is crucial in accelerating or retarding language development. Mother-initiated talk did not have these effects.

7.2 Language of reference in relation to cognition

Reference involves identifying objects in experience, representing them, and finding a way to established shared reference with the conversational partner. The earliest stage of this process, object permanence, the infant's recognition of the stability of the physical world, predates language, but later stages, in particular the issue of establishing common understanding, is related to the speaker's awareness of the knowledge and of the attentional focus of listeners. If reference to objects were the most important basis for early development of language, a major milestone would be object-permanence. Bates (1979) found instead that a more sensitive cognitive basis of language was the development of symbolic play or representation, and the child's understanding of the relation of means to ends.

7.3 Effects of talk on thought

Work in developmental psychology largely inspired by Vygotsky has focused on the relation between thought, or ideational changes, and social communication. Many types of learning and performance are being shown to be facilitated by contexts in which interaction shapes thought, including the bridging function of private speech (Diaz & Berk 1992; Hickmann 1987; Nicolopoulou 1993; Rogoff 1990; Saxe 1991; Wertsch 1985).

7.4 The relation of social development and language

There have been two dominant methods in the study of social development: questionnaires reporting self- and other-relationships, and observations, often with videotape, using global relational coding categories, often without transcript analysis. The availability of detailed transcript analysis opens up a powerful method for the study of social relationships. Differences between boys and girls in within-gender interaction in various interactional contexts have been noted at various ages (Goodwin 1990; Tannen 1990); powerful effects of friendship on interaction have also been found (Gottman & Parker 1986; Rizzo 1989).

7.5 The development of instrumental language

Early language development involves instrumental relations to others, as the priority of the action level in clause relations suggests. Even such gestures as pointing have been shown to entail understanding that the direction of gaze of the other should be toward the object pointed to. Bates (1979) found that instrumental development on a variety of measures which involved use of both people and objects as instruments could be related to early language milestones.

7.6 Egocentrism, perspective-taking, social cognition and language change

Language can be used as an instrument on the basis of the effective consequences of speech, but if learners are to match heard speech to the intentions of others, they must surmise those intentions. Experimental studies suggest slow development of awareness of the knowledge of others when it differs from one's own, and considerable individual difference throughout life. One test of this relation by Dimitracopoulou (1990) showed that in the age range 3/6–7 children's successful speech acts were related, independently of age, both to being able to imagine others' visual perspectives, and being able to guess the feelings of others. Empathic skill and awareness of the mental states of others not only develop with age, but vary with experience and, according to Dunn (1993) with instruction in families, so presumably culturally. Awareness of human causality is also implicated in the ability to relate events causally in a narrative or in other complex speech events.

Many pragmatic changes take place around 7, when most children become successful in perspective tasks. At this age children are observed to use request formulations which take into account potential problems in compliance for the addressee, as in a request formed as 'Do you have a pen I could use?', they begin to recognize complex behavior like unroutinized sarcasm, in which the surface does not match intention, and to organize humor strategically.

7.7 Play with and through language

Both adults and children use play, mimicry, and humor to display their knowledge of speech events, participation structures and style features within roles not normally their own, though there is considerable variability in enactment abilities and interest. The analysis of play is a clear convergent topic for pragmatic and developmental analysis (Kessel & Goncu 1984; Garvey 1977).

7.8 Learning social styles and identities

Andersen (1990) in studies of role-playing in English and French at various ages, found that the speech features used to mark registers change with age, beginning with phonological features such as whispering to dolls, and moving to lexical choice in occupational roles, speech acts and mitigation according to social status, and finally subtleties like topic and discourse marker choice (*well* vs. *uh*). There is accommodation outside of role play situations to addressees at least by four years of age (Shatz & Gelman 1973) suggesting social theories of addressee needs, in addition to symbolic representation through register, aggravation, or mitigation of the power and solidarity or other dimensions of the social relationship (Clancy 1986). These domains of development provide considerable opportunity for the study of social categories at various ages.

7.9 Bilingualism and bicultural development

Studies of bilingual contexts have long shown that children distinguish appropriate contexts for language differentiation from an early age, starting with noticing the setting and participant (Fantini 1985; Genesee & Nicoladis 2007). The social and contextual categories that are marked by language, by register, and other speech features are prime candidates for study by developmental psychologists (Auer 1998; Paugh 2005).

8. Collaborative research potential

There has been a move within developmental psychology as well as other fields in psychology to use the technology of videotaping, but without exploiting the information obtainable by sequential and delicate analysis of transcript and video analysis. Because of the high cost of these methods, the optimal way to bring the insights of developmental psychology and pragmatic analysis together is surely collaborative research.

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Experimentation

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1. Theoretical approaches to science

The experimental method is one of several methods that scientists in many disciplines can use to study a phenomenon. It is not superior to other methods; it simply has its own rules and domains of application. Some research questions naturally require experimentation to be answered satisfactorily, others can also (sometimes: better) be approached by relying on other research methods. Experiments can be characterized as a means to test an empirical hypothesis in a highly targeted way (experimental purpose) and as a particular way of collecting data (experimental methodology) and analyzing these data (statistics). In a sense there are two ways of studying an object of investigation: theoretical reflection and empirical analysis. Obviously, all scientists rely on observations (data); the difference between theoretical and empirical scientists mainly lies in the way they collect their data and what their targets are at the level of theoretical claims.

To distinguish empirical approaches (to which the experimental method belongs) from theoretical approaches to scientific questions, lets consider two theoretical disciplines: theoretical physics and theoretical linguistics. Theoretical physicists do not perform experiments. They rely on observations that have been made by other physicists and are aware of the physical laws that were discovered in the past. However, their goal is to find a theory or part of it (e.g., a law) that can explain the observations, or that can explain why some observations are internally inconsistent. In doing so, they try to fit the data into a theory by rigourously applying the instruments in the toolbox of mathematics or by doing the only type of experiment they want to appeal to: the so-called 'thought experiment', which is set up entirely in their mind and whose outcome is dictated by strictly following the paths of logic and previous knowledge.

Thus Newton discovered that the Moon was in orbit around the Earth because he compared it to a stone being thrown away. The resultant of the initial energy with which the object is thrown and the effect of gravity is a curve whose end point is determined by the initial energy. He imagined that if this energy were sufficient, the end point would fall beyond the Earth, as the planet has a circular form, i.e., the Earth would 'fall away' below the thrown object. When the object would start to describe a curved path towards the Earth as a result of the planet's gravity it would still not fall onto it as, once again, the curvutare of the planet would prevent this. Thus, Newton reasoned, the Moon is in a constant situation of free fall around the Earth but will never fall on it. On the contrary, it is caught in a perpetual circular orbit around it, resulting from the combined effect of the curvature and the gravity of our planet.

Einstein was a master in thought experiments and followed through on the inconsistency between the constant velocity of light, which was predicted by the electromagnetic laws of Maxwell (and had been experimentally observed by Michelson and Morley) and the Newtonian laws of movement. More particularly, a person on the platform of a station should measure a higher speed for a light beam traveling through a wagon on a passing train than for a light beam coming from a flashlight on the platform. Indeed, speeds are additive, so that the light shining through the train should pass the person on the station with a speed that is the sum of the train speed and the speed of the light beam. However, this prediction is inconsistent with the prediction made by Maxwell's electromagnetic theory, which is that the speed of any electromagnetic phenomenon is constant (about 300,000 km/s), and since light is an electromagnetic phenomenon, this prediction should also apply to light.

Einstein solved the inconsistency by a leap of genius: the realization that time and space could not be universal, i.e., spatial and temporal measurements are only valid relative to the frame of reference of the observer, such that different observers will make different measurements. If you could measure an object that is moving (fast) towards you, your measurement would be smaller than when it were not moving (so-called length contraction). Moreover, if you could sit on a moving object and compare your time measurements with the measurements made by someone who is standing still relative to the moving object, the seconds on your own clock would be ticking more slowly than those for the person standing still (so-called time dilatation).

Lets apply this to the light beam in the moving train. A train passenger holding a measuring stick of 1m and using it during a 1s time interval timed with his clock will measure that the light beam moves at a velocity of 300,000 km/h. But so will the person on the platform, who is equipped with exactly the same instruments. Still, their measurements of both the distances and the 1s interval will differ. The person on the platform will see the light beam come by and since it is moving towards him at a high speed it will be contracted. So, his measurement of the distance traveled by the light during 1s will be smaller than the distance measured by the train passenger. However, his time measurement will also differ. As the phenomenon of time dilatation stipulates that moving clocks tick more slowly, his clock will tick more quickly, and so his second will be over sooner than that of the train passenger (considered from his perspective). However, since both the numerator (distance) and the denominator (time) in the velocity ratio for the person on the platform will be shorter compared to the numbers in the ratio of the person on the train, the two ratios will be equal. The result is that both observers will disagree on their measurements of distance and time but will agree on the speed of light.

This is a verbal description of what is central in the theory of special relativity. As any verbal description, it will be a poor description from a physicist's point of view, who has mathematical formulae for transforming the measurements of the train passenger into those of the person on the platform and vice versa. However, my only intention here is to show that, purely on the basis of a daring though experiment, (really) bright scientists like Einstein sometimes arrive at formidable insights. He came to the revolutionary insight that what mankind had always believed to be true, and what Newton, the biggest scientist before him of all time, had made a cornerstone of his theory, was wrong. Time and space had to be relative to the speed of the oberver making the measurements. The only phenomenon that was apparently absolute in the universe, was the speed of light, as predicted by Maxwell's electromagnetic theory. It is astonishing that what Einstein could deduce on the basis of sheer rational, consequent, logical thinking, without doing a single experiment, has been confirmed by all experimental tests that have been performed since the year he made his discovery. It is also astonishing that he made this discovery in his spare time, in a period when he was working at a Swiss patent office (not at a university or a research institute). It is all the more astonishing that he was only 26.

These examples demonstrate that great advances have been made in sciences like physics through rigid and clear logical reasoning. Theoretical approaches have also been followed in the study of language. As a matter of fact, the great philological tradition, which gave rise to, for instance, the discovery of Verner's law and the principles behind the Great Vowel Shift, is an example of theoretical linguistic work in which scholars attempted to find principles or laws that covered many diachronic and/or reconstructed lexical data. Also, the major linguistic theory of the twentieth century, Chomsky's generative grammar, is a highly theoretical approach to the study of language. Irrespective of one's personal evaluation of Chomskyan linguistics and whatever the ultimate truth of its main tenets will be (they will probably be wrong, see the introduction to this volume), Chomsky's theoretical exercise is admirable for several reasons. He made the ultimate goal of linguistics one of explaining the facts on the basis of deep-set principles rather than one of providing an accurate description of the language data. Additionally, his work spawned or refuelled several empirical lines of language investigation (even though this was sometimes because his statements were initially misunderstood), like language acquisition, typology, psycholinguistics, neurolinguistics, computational linguistics, and several more. Chomsky never did an experiment. He set out from a sample of mind-boggling sentences (e.g., *I like flying planes*), at least for linguists from previous linguistic schools, and argued that language users must possess syntactic principles without which they would be unable to understand language unambiguously. Moreover, he argued, these principles cannot be induced from the impoverished language input to the child so quickly because there are in principle too many ways to explain why sentences in your native language are built the way they are (i.e., to construct a mental grammar) that no child would be able to speak its native language by the time it enters kindergarten (but see again the introduction to this volume for recent experimental work rejecting this position, see also the chapter on Language Acquisition). This line of reasoning resulted in the concept of an innate, hence universal, set of syntactic principles that are hard-wired in the form of a genetically predisposed language faculty.

Despite the fact that neither theoretical linguistics nor theoretical physics are driven by empirical research, claims in the former discipline tend to be more vulnerable to debate and rejection by fellow researchers. Although this is an interesting topic in itself, suffice it to say here that the derivation of theoretical statements through the application of mathematics (physics) rather than through the application of plausibility arguments (linguistics) makes it *a priori* harder to refute a theory in physics than a theory of language. Since language is also a highly multi-faceted phenomenon (internal structure, usage purposes, usage requirements in the form of various types of cognitive resources and processes), a theory of language often reflects a researcher's preference for one of these facets. As an aside, it would be interesting to investigate why there is much more consensus among reseachers on the very foundations that actually define the discipline in sciences like, for instance, physics compared to sciences like, for instance, linguistics.

2. Empirical approaches to science

Empirical science is the obvious counterpart of the theoretical study of an object of investigation. Basically, there are two methods of empirical investigation: collecting a corpus of data and designing an experiment. Neither methodology is superior to the other. The choice between the two is simply motivated by the nature of the research question. Some questions require corpus research because an experiment is by definition impossible. For instance, seismologists who want to know whether a pattern can be discovered in the distribution of earthquakes and their magnitude have access to a large database of these events and their magnitude since the time of their registration (their corpus) and have to use this to discover a possible pattern. Obviously, they would not be able to set up an experiment. In the domain of language, someone who wants to describe language acquisition by the young child would collect a large database of utterances over a couple of years (preferably from different children) and make an inventory of the words, word types, and constructions (and many more aspects) that are produced at each age level together with their usage frequency. This will allow the researcher to answer two questions: whether a language unit is used and which frequency it is used with. Similarly, language researchers may be interested in a corpus of speech errors of experienced language users, with the goal of finding out what these data can tell us about the cognitive infrastructure behind language. By doing so they set out from the rationale that an error type is only possible because the structure of the internal system makes it possible and, hence, that 'reasoning back' from the errors one can discover the internal structure of the processing system. The taxonomy of errors and the 'logical' relationship between them made it possible for pioneers in speech production research (Fromkin 1973; Garrett 1975) to set up a fairly detailed structure of the language production system. Note that an added advantage of corpus research is that the observations are made under natural conditions of language usage. In short, corpus research is called for whenever one is interested in the set of theoretically interesting events in a domain, their occurrence probability and ‘size’ (magnitude, frequency), and, when applicable, the way they interact.

A potential disadvantage is that researchers are restricted to the actual data in the corpus. For instance, if a language researcher wants to know whether a three-year old child is capable of using a particular construction X, the absence of X in the corpus does not amount to a negative answer. Perhaps there were no situations that invited the child to use this construction or perhaps the child preferred other constructions instead, while still being able to use construction X. When such a situation arises, an experiment could be designed to arrive at a more conclusive answer. For instance, if the target construction can be elicited by pictures, one could show a sample of children a set of pictures, some of which strongly encourage the use of the construction under investigation and others that don’t, and see whether and how often the children use the construction.

This does not mean, of course, that the experimental method is only a fall-back option for cases when corpus analysis meets its limits. Just like corpus analyses are the best, or even only, means of gathering data for addressing some research questions, so is experimentation sometimes the best or only way of studying a hypothesis. Let me, once again, give an example from a different discipline, to make it clear that we are talking about general principles of doing science, rather than principles that apply to the study of language only. For instance, in Newton’s time it was well-known that a prism broke a beam of white light into the spectrum of colours. The observation was a familiar one but not its explanation: was it the prism that had unknown, almost magical, qualities, so that it transformed white light into a set of rainbow colours, or was a bundle of white light a perfect blend of all colours, which could only be ‘unblended’ by a prism? Note, by the way, that to many it must have seemed *a priori* less plausible that all colors are ‘hidden’ in white light (*“Red, blue, and green in white light?”*) than that the special geometrical properties of a prism produce colour where there is none to begin with. The only way for Newton to find out was to do an experiment, a simple but quite ingenious one. The logic was impeccable. If the geometry of a prism transforms one type of light into a series of colors, the same should happen when one of the colours coming out of a first prism (e.g., red) is isolated and sent separately into a second prism. Then, too, some magical transformation should occur. On the other hand, if white light is an amalgam of all colours and the geometry of the prism does not add colours but merely separates colours that are already there from the start, then sending a red light ray through a second prism should not affect the colour of the outcoming bundle of light, i.e., it should remain red. Newton observed the latter and thus demonstrated experimentally that white light is (rather counter-intuitively) a mixture of all colours of the rainbow. Note, as an aside, that many great scientific discoveries are counter-intuitive. When following the course of the Sun against the sky, virtually everybody would conclude that the Earth stands still and the Sun turns around it. We know that we are fooled by our intuitive interpretation of our perception and that the Earth is on an orbit around the Sun, because this is what we have been taught at school, due to the careful analysis of astronomical observations by scientists. Interestingly, a hypothesis that seems self-evident is often wrong.

As is the case in physics and so many disciplines, experimentation can be the only methodology to address particular questions in language research. Reseachers who want to know whether it is more difficult to read reduced relative clauses (*the horse raced past the barn fell*) than their counterparts containing an explicit relative pronoun (*the horse that was raced past the barn fell*) cannot study this question by asking people how difficult these two sentence types are in their perception. The best they can do is set up an experiment in which, for instance, participants have to read sentences with reduced and unreduced relative clauses while their reading time on each word is being registered as a measure of local processing difficulty. The time it takes to read the word following the first noun in the relative clause (*horse*) would make it possible to answer the experimental question.

3. Experimentation

In a nutshell, experimentation can be described as (i) a methodology for testing a hypothesis (ii) by systematically manipulating one or several factors that are supposed to affect the study object, (iii) by collecting data with respect to these factors on a measure that is assumed to be objective and (iv) using one or more statistical tests to process these data so as to (v) relate the outcome to the initial hypothesis. The advantage of this methodology is the high degree of control on the part of the experimenter, who determines what is manipulated and what remains constant in the experiment. As a result, factors whose interaction is often hard to tease apart in the complexity of real-life situations can be methodologically separated and their relative importance assessed independently, unlike what is the case in corpus research. At the same time, experimenters must pay a price for this control, as it often imposes serious restrictions on the materials that can be used. As a result, great care needs to be taken to avoid unnatural and, by implication, unrepresentative samples of linguistic material. However, if the researcher can avoid this trap, the experimental method is a very powerful one and can sometimes shed light on problems where other methodologies are not suited for.

In what follows I will sketch the most important concepts of the experimental method, both from the perspective of its design and data processing. First, I will discuss important issues of experimental design. Second, I will explain the basic rationale behind statistical testing and discuss some of the most commonly used statistical tests. While writing the sections below I have made use of the following books on experimental design and statistical testing in the behavioral sciences: Baayen (in press), Kirk, (1982), McCall (1970), and Siegel (1956).

3.1 Issues in experimental design

3.1.1 *Operationalization of the experimental hypothesis*

A major step is to translate one's hypothesis into a testable prediction. This is the stage of so-called operationalization. The necessity of such a translation is quite straightforward. Any hypothesis with respect to a study object must be falsifiable. This means that it must make a clear prediction about what should be observed in the empirical world if the hypothesis is true. Because a hypothesis is often couched in abstract concepts the first task of an experimenter is to map these abstract concepts onto observable factors.

The first question to ask is: how can I measure the concept I want to study? Take, for instance, the example of relative clauses mentioned above. The hypothesis is quite abstract: reduced relatives are more difficult to read than non-reduced ones. How does one operationalize 'reading difficulty'? Following a long tradition in psycholinguistics a legitimate answer would be: the time it takes to read the first (and following) word on which the difficulty should become apparent to the reader. In a sentence like *The doctor investigated by his colleague was seriously ill,* this would be the time it takes to read the preposition and subsequent words in the *by*-phrase. The prediction is that, due to the processing problem that is expected on the *by*-phrase – initially *the doctor* is likely to be interpreted as an agent whereas the *by*-phrase makes it clear that it is a patient – this reading time is longer than in the equivalent sentence with a non-reduced relative (*The doctor who was investigated by his colleague was seriously ill*). However, operationalizing the concept 'reading difficulty' as the time it takes to read a word in reduced versus non-reduced sentences only shifts the problem to another question: how does one measure the time it takes someone to read a word and to update the evolving syntactic structure of the sentence?

As language processing is an internal event, imperceptible to an outsider and often even beyond the conscious awareness of the reader himself, experimenters must rely on some form of observable behaviour that plausibly correlates with the mental process under study. Often this observed behaviour takes the form of a simple task, like the pressing of a button. For instance, when studying the reading difficulty of reduced relatives this task could be so-called self-paced reading, where the words of a sentence are presented one by one, each following a button press by the participant, such that participants read the sentence at their own pace (hence, self-paced). The reading time for a word is defined as the time elapsing between the onset of a word and the participant's button press that makes it disappear. The assumption behind the technique is that readers incur a reading time cost or gain whenever a factor complicates or facilitates the processing of a word (see, for instance, Ferreira & Henderson 1990; Koornneef & Van Berkum 2006; Trueswell 1996). So, when using the self-paced reading task to study the hypothesis that increased reading difficulty is associated with reduced relative clauses, this hypothesis would be operationalized in the form of the following prediction: "The average reading time on the *by*-phrase will be significantly longer for reduced relatives than for non-reduced ones".

Note that the level of granularity of these measurements should be determined too. For instance, when the goal is to measure temporary reading difficulties one should be aware of the high speed at which mental processes take place and, hence, the short-lived nature of a momentary reading problem. As a result, reading times should be measured at the millisecond scale.

3.1.2 *Independent and dependent variables*

A variable is a dimension that can take different 'values' and, hence, makes it possible to distinguish different categories in an experimental set-up. A distinction can be made between categorical and continuous variables. Some categorical variables have a dichotomous nature (gender: male-female, species: human-ape) whereas others form a continuum (word frequency, intelligence, second language skill, motivation), even though, in practice, continuous variables are often turned into categorical ones by dividing the continuum into discrete regions, generally corresponding to the extremes on the continuum (e.g., high-frequency vs low-frequency words).

A basic terminological distinction in the vocabulary for talking about experiments is the distinction between two qualitatively different types of variables in the experimental design: dependent and independent variables (sometimes the name 'factors' is used as well). *Dependent variables* are metrics, chosen by the experimenter, with the rationale that they are able to measure crucial aspects of the object of inquiry. The choice of a dependent variable is to a large extent determined by the nature of the experimental task, which in turn is selected for its presumed capacity to probe the nature of the study object. For instance, if one is interested in the time it takes for lexical access to take place (e.g., in written or spoken word recognition) one must choose a task that can make this mental event objectively observable, or at least, closely approximate it. In psycholinguistics this has often caused the development of experimental methods in which participants have to perform a simple task on the language stimulus: push a button in a word-nonword discrimination task (lexical decision), read a word aloud (naming), identify an initially imperceptible word (progressive demasking), name a picture (picture naming), etc. These are all extremely simple tasks, serving a double purpose: (i) force the participant to perform the mental process under study (e.g., lexical access; hence, the task to discriminate words from nonwords with the concomitant obligation to contact the mental lexicon) and (ii) simplify participants' performance to a level where they need to appeal to as few extraneous mental processes as possible. Experiments of this kind enable the use of two dependent variables: (i) a reaction time variable, which reflects the time (in milliseonds) that elapses between the onset of the language stimulus and the participant's response to it (or the initiation of this response, as in the case of word naming, for instance) and (ii) an error variable, which reflects the correctness of the response. There are also other types of dependent variables (e.g., eye fixations), but we will postpone that discussion till the next paragraph.

Besides dependent variables, there are variables that determine the design of an experiment. These are referred to as *independent variables* and are directly related to the theoretical motivation behind the experiment, i.e., they are introduced into the experimental design because researchers have reasons to believe that they have an impact on the phenomenon under study. For instance, when researchers hypothesize that the number of morphologically related words of a monomorphemic word (e.g., *mankind, manhood, sandman, snowman,* *strawman,* etc. for the word *man*) might affect participants' recognition speed of the word in a lexical decision task (faster responses to words with large morphological families) they can investigate their hypothesis by introducing this factor as an independent variable in their experimental design and make a contrast between words with large morphological families and words that have only a small numbers of morphological relatives (Schreuder & Baayen 1997). Thus experimenters choose their independent variables because they think they are theoretically important and manipulate them so as to create different *conditions* in the experiment, where the term 'condition' stands for a particular level of an independent variable. There can be two (e.g., high-frequency vs low-frequency words), three, or more conditions per independent variable.

When independent variables are continuous in nature, experimenters have to make an important choice: either they cut up the continuum into two or more 'regions' or they make sure that their materials are sampled from the whole range covered by the variable. The first practice is referred to as factorizing a variable and, not surprisingly, this leads to an experiment with a *factorial design* (as discrete variables do; e.g., an experiment comparing high-frequency and low-frequency words). The second practice is referred to as the technique of the *regression design,* in which the impact of the independent variable on the dependent one is measured along the whole continuum (offering a complete picture of the relationship between the two) rather than at a limited number of 'points' on this continuum (e.g., sampling words from all frequency bands). Pyscholinguists like Harald Baayen have argued that a regression design should be preferred over a factorial design (e.g., Baayen in press, Cohen 1983).

3.1.3 *Choosing the dependent variable: How to best tap into the targeted process*

Often problems abound when trying to find a good dependent variable on which to measure the critical concept in the hypothesis. The reason is simple: when attempting to measure a mental process one must try to stay as close as possible to the execution of this process, which is not an easy challenge. As we will see, there are different types of tasks (see also the chapters *Cognitive Science* and *Psycholinguistics* in this volume).

One general type of task, already mentioned above, requires participants to make their response contingent on the output of a decision component, which generally means that they have to press a button once they have made the kind of decision that the experimental task calls for. Lets return to our example of reduced relatives and the use of self-paced reading. Obviously, the requirement to execute another task than reading itself, i.e., pushing a button to move on to the next word, with the purpose of making the end of the word recognition process observable to the experimenter (assuming the existence of a strong correlation between completing word recognition and pushing the button), necessarily involves a decision on the part of the participant. In self-paced reading this is the simple decision that the current word has been integrated into the previous sentence part and that one can move on to the next word. Similarly, a lexical decision task requires participants to discriminate letter strings in their language (words) from made-up instances (nonwords), which obviously involves a decision, allbeit a relatively simple one.

The use of the word 'simple' in the previous sentences is important. It is mandatory that the decision component of the task be kept as simple as possible. The more complex a decision is, the more (theoretically irrelevant) mental processes will become part of the time registrations. The presence of such 'noise' in the data increases the likelihood that the correlation between the time measurements and the theoretical component under study that one is looking for (e.g., How long does syntactic processing take? How long does lexical access take?) will be undetectable. Indeed, once additional mental processes are an integral part of the response times, there is no way to separate them from the temporal components that are targeted by the experimental design.

Even though a lot of insights have been gained through the use of button-pressing tasks, the last decades have seen a rise in the use of techniques that arguably measure mental activity in a more direct way. The eye-tracking technique, for instance, has become quite popular, especially in the study of online syntactic processing. The basic assumption behind this method is that eye fixations are fairly reliable indicators of ongoing mental processes, as the eyes tend to fixate what the brain finds interesting/informative at that particular moment in time. So, eye tracking research is driven by the assumption that "what is being fixated is being processed". Technically, this technique makes it possible to determine the fixation point of the eyes on a computer monitor at a frequency ranging between several hundreds to one thousand times per second (i.e., once per millisecond!), depending on the technical possibilities of the apparatus. In psycholinguistic studies, participants' fixation times on a word are treated as a direct reflection of their mental processing load on that word (for studies relying on this technique see, for instance, Clifton & Staub 2008; Fischer, Murray, & Hill 2007; Pollatsek, Juhasz, Reichle, Machacek, & Rayner 2008; Pollatsek, Rayner, and Reichle in press, Rayner & Pollatsek in press, Rayner, Chace, Slattery, Ashby 2006; Rayner, Pollatsek, Drieghe, Slattery, & Reichle 2007; Staub & Rayner 2007).

Besides offering the promise of directly reflecting mental activity, eye fixations are also less vulnerable to the impact of participants' (conscious or unconscious) decisions to perform the task differently than required by the experimenter, the major weakness of many button-pressing experiments. For instance, participants in a self-paced reading task can develop their own rhythmic pattern of button pressing, while temporarily storing the words in their working-memory and covertly processing them there. However, people seem to have far less control over their eye fixations, which typically remain on the fixated object (here: word) as long as information from that object needs to be taken in.

Measurement techniques that are supposed to be even more sensitive to the underlying mental processes are methods of brain imaging, which provide a picture of the dynamics of brain functioning while language processing is going on. I will not enter into specifics here (see the contribution on *Cognitive Science* for more details). The use of ERP (Event-Related

Potentials, i.e., that part of the electrical activity at the scalp that is tied to the occurrence of a specific event) and fMRI (functional Magnetic Resonance Imaging) have become the most popular techniques in attempts to relate aspects of language processing to dynamic processes in the brain. However, although a lot of progress has already been made, novel techniques naturally bring along their own problems. It is not fully clear yet how the images of brain activity should be related to the underlying mental processes, nor is there a simple algorithm for mapping visualizations of brain activity onto individual mental processes. This should be no reason for pessimism, as it is the normal state of affairs in any novel research field. Moreover, a broad consensus has already been reached on a number of issues as well. For instance, most researchers adopt the view that, in ERP research, components like the N400 (a negative deflection in the electrical signal registered from the scalp around 400 ms poststimulus onset) and the P600 (a positive deflection in this signal around 600 ms poststimulus onset) reflect semantic and syntactic violations in sentence processing, respectively.

Over the past years, some research centres have made it their primary research goal to study brain activity during ongoing language processing. The *Donders Institute for Brain, Cognition and Behaviour* in Nijmegen is probably the best known centre of this type, housing the Centre for Cognition, the Centre for Cognitive Neuroimaging and the Centre for Neuroscience. Its building was erected at a short walking distance from the well-known *Max Planck Institut für Psycholinguistik* at Nijmegen. Another centre that systematically publishes its findings in high-quality journals is *The Neurocognition Lab* at Tufts University in Boston (Massachussets), which is specialized in ERP research on language processing. Here is a sample of recent publications coming from these two research centres: Grainger & Holcomb 2009, Hagoort 2008, Holcomb & Grainger 2009, Midgley, Holcomb & Grainger 2009, Van Berkum, Van den Brink, Tesink, Kos, & Hagoort 2008, Willems, Őzyürekand, & Hagoort 2008.

3.1.4 *The orthogonal experimental design*

Although there is a large variety of experimental designs, one of the most popular ones in psycholinguistic research is a design in which the various independent variables are crossed or, in technical language, are *orthogonal* to each other. This simply means that all conditions that are logically possible are studied in the experiment. For instance, an orthogonal design with two independent variables A and B will investigate the experimental situations that are defined by crossing all conditions on variable A with all conditions on variable B. Such designs are easy to visualize. Thus an orthogonal design with the independent variables A and B, with 3 conditions on each variable, can be visualized as a square with nine cells, obtained by crossing the 3 conditions on each variable. An orthogonal design with three independent variables A, B, and C, with respectively two, three, and two conditions, can be visualized as a two by three by two cube, representing the 12 conditions in the experiment.

Take the following concrete example. A psycholinguist might be interested in whether readers respond faster to a target word when it has just been preceded by another word (a so-called prime) to which it bears a strong associative relationship (e.g., *cat-MOUSE*) and whether this effect is the same when the target word has a high or low occurrence frequency in the language. This is an instance of a 2 by 2 (also 2×2) design, with the independent variables Relationship (two conditions: associative vs. unrelated or baseline) and Frequency (two conditions: high vs. low frequency). Thus, observations will be made on low-frequency words, both in a control and associative condition, and on high-frequency words, also in a control and associative condition. As a result, the researcher will be able to find out whether an associative effect is present for words of each frequency type and whether the magnitude of these effects is the same.

Note that orthogonal designs are an instance of the factorial design type that was mentioned earlier (see 3.1.2). While offering a lot of control to the experimenter and building in sharp contrasts between conditions by factorializing the independent variables (thus maximizing the opportunity for measuring effects), this design type has been criticized for a number of reasons. Readers who are interested in this issue are referred to Cohen (1983) and Baayen (in press).

3.1.5 *The concept of matching and the necessity of a control condition*

The preceding example allows us to introduce another crucial concept at the level of experimental design: the notion of a *control condition,* which is itself related to the more general concept of *matching.* The best way to think of a control condition is by considering it as a baseline against which the other conditions on the same independent variable can be assessed. This means that the only way to test the validity of an experimental hypothesis is by making a comparison between conditions. When thinking about it, this is obvious, as one can only state that a condition is theoretically important if one can demonstrate that it behaves differently (i.e., gives rise to different measurements) than a condition that is neutral with respect to the other conditions on the same independent variable. For instance, there is no way to demonstrate that an associative relationship between a prime and a target word speeds up recognition of the target if this is not compared to a condition where the same target is preceded by a word without an associative relationship to that same target (each condition is instantiated by many such prime-target pairs).

Consequently, because hypothesis testing inevitably involves a process of comparison, the prediction emanating from an experimental hypothesis is always framed in the terminology of comparative adjectives like 'faster than', 'more than', 'larger than', 'longer than', etc., followed by the name of the control condition. For instance, the hypothesis behind the associative priming experiment can be formulated as follows: "In a lexical-decision task, the average reaction time to target words will be faster when they are preceded by an associatively related word (*cat-MOUSE*) than when they are preceded by an unrelated control word (*lap-MOUSE*)". Note that, as a corrolary of the comparison process, the absolute reaction times (RTs) are quite irrelevant. What matters is the relationship between these RTs in the critical and the unrelated conditions: which average RT is faster and is the observed difference large enough to be significant? (see Section 4)

The control condition differs from the critical condition(s) in one respect only: the property that makes the independent variable theoretically interesting. In the example of reading reduced relatives, the control condition consisted of sentences in which the relative clause was not reduced, whereas in the example of associative priming the control condition consisted of prime-target pairs where the prime was not associatively related to the target. Importantly, this should be the only difference between the control condition and the critical condition(s). When they differ on more dimensions that affect the dependent variable, it is no longer possible to attribute the obtained effect to the variable of interest. This means that the critical and control conditions should be *equated* as much as possible on all other variables that are known to affect measurements on the dependent variable.

For instance, in the example of associative priming, the control primes should be matched to the associative primes on all factors that could affect reaction times (RTs) to the subsequent targets, except for the strength of the prime-target association (which should be absent for the control primes). This means that the primes in the two conditions should be equally long and occur with a comparable frequency in the language, as both length and frequency are known to determine lexical processing time. If the control primes were longer and/or less frequent than the associative primes, participants would take longer to recognize them and, as a result, would be less ready for reading the target than participants in the associative condition. This would be reflected in shorter RTs in the latter condition. However, the observation of an effect of 'associative priming' would be due to poor matching rather than to the associative relationship between primes and targets. Or, more correctly formulated, it would be impossible to decide whether the result had been caused by the associative prime-target relationship or by the poor matching.

The take-home message is that tight matching between the control and critical conditions on the same independent variable is necessary to guarantee that the effect of a critical condition can be unambiguously attributed to the manipulation of the independent variable. Hence, one must be able to arrive at statements of the following type: "Words are recognized faster when they are preceded by an associatively related word than by a control word, *everything else being equal*".

3.1.6 *Manipulations within or between participants (or items)*

When setting up an experiment in order to test a hypothesis one does not only have to think about the best dependent variable, the important independent variable(s), the conditions that are relevant on this (these) variable(s), the control condition and the necessity of matching, one also has to make a decision regarding the type of manipulation. There are two ways of manipulating an independent variable. While the distinction described below may appear obvious, the reader should bear in mind that the choice for one manipulation or another has immediate consequences for the statistical analysis of the data and, correspondingly, the chance of obtaining statistical significance. A within manipulation (if possible) should be preferred to a between manipulation because it is the most powerful one from a statistical perspective.

A distinction is made between manipulating an independent variable *within* or *between* the units on which experimental measurements are made. In any language experiment two kinds of such units are used: a set of participants and a set of language items (e.g., words, sentences), both of which should be representative samples of the populations they are drawn from. Note that the term 'population' is a technical term for referrring to the set of all possible participants in the world meeting the selection criteria (e.g., age, education) or the set of all items satisfying a particular constraint. Hence, an independent variable can be manipulated within or between participants, and within or between items. The term 'within' refers to the fact that the same participant or language item is tested in all conditions of an independent variable, whereas the term 'between' refers to the fact that different participants or items are tested in the different conditions of an independent variable.

Because definitions like these always sound more abstract than the concepts they define really are, lets give some illustrations. A researcher who wants to know whether the speed of word recognition differs between boys and girls at the end of the first grade could compare 30 boys and 30 girls and measure their RTs to correct word responses in a lexical-decision task ("Is this a word or not?"). The independent variable of interest, Gender, is obviously manipulated between participants, each participant being either a boy or a girl. However, it is manipulated within items, as each item is presented to members of both the male and the female condition. Consider another example. A researcher who wants to find out whether the frequency effect in word recognition, i.e., the finding that high-frequency words are recognized faster than low-frequency ones, is the same for people in different age ranges (31–40, 41–50, 51–60) would select, say, 20 words for each frequency type and 30 people from each age group, thus filling up a 2×3 orthogonal design. When each participant sees all words from both frequency classes, the independent variable Word Frequency is manipulated within participants. However, it is necessarily a between-items variable, as each item either belongs to the low-frequency or the high-frequency category. Conversely, the independent variable Age Group would necessarily be manipulated between participants, as each participant belongs to only one group. On the other hand, it would be a within-items variable, as each participant in the three age groups would see all items from both frequency groups.

The above examples suggest that the distinction between a manipulation within or between participants/items is more or less obvious. Obviously, a participant belongs to only one gender or age group (hence, between-participants manipulation) or an item only to one frequency category (hence, between-items manipulation). Equally obviously, when one wants to know whether a single participant group responds differently to two or more different item types (e.g., reduced vs unreduced relatives, high vs low frequency words) the manipulation of the independent variable Item Type is within participants. And obviously, when one wants to know whether a single item group is responded to differently by different participant groups on an independent variable (e.g., gender, age) the manipulation of the independent variable Participant Type is within items.

Note that the decision between a within or between manipulation is not always so obvious, and certainly deserves sufficient thought if one does not want to set up the wrong design. A rather extreme example will make this clear. In the imaginary experiment mentioned above, where word frequency and the nature of the prime-target relationship are orthogonally manipulated, one could, in principle, also manipulate the frequency variable between participants. More particularly, one could present the low-frequency words to one half of each age group and the high-frequency words to the other half. Clearly, however, that would be a wrong decision, as participants in the two subsets could differ in their average response speed. As a result, an observed frequency effect could reflect the effect of word frequency on processing time as well as differences in participants' response speed (or both). To avoid such problems, the frequency variable must be manipulated within participants in such an experiment. As said, this is an extreme example, but quite often more subtle issues crop up and require thoughtful deliberation on the question of within versus between manipulation. In experiments involving language materials researchers are often confronted with one particular type of problem involving this methodological choice. This brings us to the last theoretical concept in this section: *counterbalancing.*

3.1.7 *The counterbalancing technique*

Suppose that a psycholinguist wants to know whether a suffixed derivation like *singer* is automatically decomposed into its constituent morphemes before the word itself is accessed in the mental lexicon (prelexical decomposition, see e.g., Longtin, Segui, & Hallé 2003; Diependaele, Sandra & Grainger 2005). In order to find out, she reasons that a prelexical decomposition process should be blind to lexical knowledge. Indeed, at a prelexical level, the processing system has no access to information on the lexical or grammatical properties of a letter string (e.g., that –*er* is a suffix). Hence, decomposition should apply irrespective of the fact whether the whole word is a true derivation (*singer*) or not (*corner*).

The researcher decides to use the masked priming technique to address the issue. This presentation technique makes conscious perception of the prime impossible by superimposing three visual stimuli on a computer monitor: the prime is presented in lowercase letters for only 60 ms, is preceded for 500 ms by a series of hash marks (#####), and is immediately followed (overwritten) by an uppercase target (Forster & Davis 1984; e.g., *##### singer SING*). The technique owes its name to the fact that, just like a mask hides a person's identity, the preceding and following stimuli and their duration prevent participants from becoming aware of the prime's identity. The purpose is to deny participants the chance to discover the nature of the critical prime-target relations and prevent them from using this knowledge to treat the prime words as valid cues with respect to the upcoming target. For instance, suppose that the primes were visible and that, in an extreme case, 75%

of the prime-target pairs were morphologically related. Obviously, in such a situation a prime would have a very high cue-validity and predict a morphologically related target in 3 out of 4 cases. This might cause participants to make faster target responses compared to a situation where they could not make conscious use of the primes (see Forster and Davis 1984, for a convincing demonstration in the context of identity priming).

In such an experiment one needs at least two sets of target words: stems from true derivations (*sing* from *singer*) and 'stems' from pseudo-derivations (*corn* from *corner*). These instantiate the conditions of the independent variable Target Type. However, in order to make sure that priming effects result from morphological decomposition rather than from orthographic priming (repetition of an orthographic sequence) an extra condition on the variable Target Type is desirable, more particularly, one where a target word is also embedded in the prime's leftmost position but the prime cannot be described as the concatenation of two potential morphemes (*sandal-SAND*). One then needs to think about the nature of the primes that are needed. For each target two primes are required: the word containing the target string (derivation, pseudo-derivation, or orthographic prime) and a matched control prime that does not contain the target. Obviously, one can only know whether, for instance, priming the target *SING* with the prime *singer* causes faster response times and/or fewer errors when a control condition is included for comparison. The two types of prime words represent the conditions on the independent variable Prime Type.

So, in order to be able to answer the research question, the researcher needs to orthogonally combine three target types with two prime types (2×3 design). For each target type, the priming effect will be defined as the difference between the average RTs in the critical and control prime conditions. The statistical significance of this effect (see Section 4) will answer the question whether recognition of this target type benefits from the embedded word in the preceding prime or not. A comparison between the priming effects for the three target types will make it possible to identify the nature of the priming effect. When the three priming effects do not differ from each other, the effects will be orthographic in nature. When priming is only obtained for the two conditions whose final letter string is homographic with a suffix, the priming effect will be morphologically constrained, although not in the linguistic sense of the term. Indeed, it will reflect the effect of a blind process of prelexical morphological decomposition, as primes like *corner* are no true derivations. Finally, when priming is restricted to the condition with true derivations as primes, this outcome will indicate that the effect is situated at a processing level where a distinction can be made between the morphological and non-morphological status of a suffix-like letter pattern, i.e., the mental lexicon.

Ideally, one would want to present each target with its two prime words to each participant. However, this would be a big methodological mistake, as participants respond faster to the second presentation of the same target word than to its first one, even when these targets are separated by many trials (Forbach, Stanners, & Hochaus 1974) or even by two days (Scarborough, Cortese, & Scarborough 1977). One might attempt to solve this problem by presenting half of the targets with their control prime on their first presentation and the other half with their critical prime on the second presentation (reversing this assignment of control and critical primes to targets for half of the participants). However, this might be a bad idea as well because one would be unable to remove the repetition effect, and its size might be too large to leave room for the (much smaller) masked priming effect to surface in the data.

The standard solution that is opted for in situations like these could be described as 'having one's cake and eat it'. The set of participants is divided into two equally large groups (A and B) and so is each of the different item sets (Half 1 and Half 2). Participant group A receives Half 1 of each target type with its critical prime (e.g., *singer-sing, corner-corn, sandal-sand*) and Half 2 with its control prime (e.g., *spoiler-dream, sister-rash, candle-need*). In contrast, participant group B receives the opposite assignment of target words to control primes (e.g., *winter-sing, filter-corn, kettle-sand*) and critical primes (e.g., *dreamer-dream, rasher-rash, needle-need*). Table 1 below visualizes the design structure of an experiment with a counterbalanced design:

Table 1. The structure of a counterbalanced design

	Participants A	**Participants B**
Item Half 1	CONTROL	CRITICAL
Item Half 2	CRITICAL	CONTROL

Thus when restricting our attention to the two priming conditions (critical vs control), each participant has contributed RTs to both conditions equally, more particularly, to 50% of the items. Similarly, each item has been presented in both conditions equally often: in the critical condition in one participant group and in the control condition in the other participant group. This is important for comparing the average RTs in the two conditions, as these averages will now reflect properties of all items (degree of difficulty) and properties of all participants (average reaction speed) to the same extent. The result is that this technique makes it possible to avoid item repetition effects, while still ensuring that the difference between the critical and control conditions can be solely attributed to the manipulation of the independent variable.

This technique of counterbalancing is an ideal solution when a single participant must not see the same target in different conditions. However, note that this solution still allows for both a within-participants and a within-items manipulation of the critical independent variable, i.e., the most powerful manipulation from a statistical perspective. Prime Type is manipulated within participants, as each participant sees half of the items from the three Target Types with a critical prime and the other half with a control prime. Prime Type is also manipulated within items, as each item is presented with its critical prime to half of the participants (say, Group A) and with its control prime to the other half (say, Group B).

3.2 The rationale behind statistical significance testing

From time to time most people are confronted with statistics. For instance, they hear in the news that there has been an increase in unemployment of 5% or that the number of cars sold in the past year decreased by 30%. In magazines or newspapers they take notice of the percentage of cigarette smokers and drug takers between the ages of 12 and 20 or the percentage of people dying in a car versus plane crash (and the derived numerical risk per drive or flight). These are descriptive statistics. They merely provide us with a numerical description (and sometimes visualization) of different conditions on a variable (age, year, type of vehicle) and thus make it possible to see differences between these conditions. Often such descriptive statistics are informative, and managers, policy makers, and individuals can all be alarmed or comforted by looking at the decreases or increases across time or at large differences between two conditions.

However, whereas descriptive statistics show us differences, they do not tell us whether these differences are sufficiently large to attach much importance to them. They cannot tell us such things, as these fall beyond the scope of descriptive statistics. Rather they belong to the territory of explanatory statistics. It is explanatory statistics that experimentalists turn to when they have to assess the theoretical importance of their measurements.

Suppose that the outcome of our associative priming experiment is an average response time of 561 ms in the control condition and 538 ms in the condition with associative primes. At the level of description it is clear that associative primes facilitate responses (23 ms advantage). However, how can we decide whether this quantitative difference corresponds to a qualitative difference, i.e., a difference that matters at the level of model construction? Does this difference support the *theoretical* claim that associative primes speed up lexical access and that, in order to do so, the mental representations of associatively related words must ‘somehow’ be connected to each other in the mental lexicon? Would a 10 ms advantage support this claim? Or do we need a 50 ms advantage? In other words, how large must a difference between conditions be before it can be proclaimed theoretically relevant? Answering this question is the goal of each statistical test. Importantly, each statistical test is founded on the same basic logic. Once one comes to grips with this logic, one understands the rationale behind statistics in general and, hence, each statistical test in particular. One does not need to understand the mathematical foundation of the test to appreciate the meaning of its output values. It is to this logic that we will now turn.

3.2.1 *Basic assumption: The observed difference is due to chance*

Lets start from a very simple fact: whenever one compares two conditions (e.g., IQ of 16-year old boys and girls, reading times in reduced and non-reduced relatives, lexical decision times after associative or control primes, etc.) we expect to find a difference, no matter how small, between the groups. Imagine that you had to give the same dictation to two classes of equally old children, containing the same proportions of boys and girls, following the same type of education in the same school. You will agree with me that you would be very surprized if the average scores in the two classes were exactly identical. Or consider this. If someone accused you of having given him a false coin by showing you that in a series of ten tosses the outcome is 6 times 'head' and 4 times 'tails' you would not be impressed by such a small difference. Rather you would expect this to happen, even with the most perfect of coins and completely honest tosses. In other words, the probability of finding a difference between two conditions (class 1 vs class 2, heads vs tails) is larger than the probability of finding exactly the same result.

This is a trivial yet important starting-point because it helps us conceptualize the fundamental rationale behind statistical testing. The whole statistical enterprise is built on the following facts:

i. a difference between conditions is to be expected, even if there is no qualitative difference between the conditions (think of the 6/4 outcome in the coin tossing test);
ii. when only chance factors are at play, they will not only produce small differences, the possibility of extreme differences also exists. For instance, if one keeps running series of ten consecutive coin tosses with a fair coin, it will occasionally happen that the outcome of all ten tosses is 'heads' or 'tails';
iii. one can calculate all theoretically possible differences between two conditions and their associated probability of occurrence, by considering each measurement (e.g., outcome coin toss, average dictation score) as the result of pure chance;
iv. one can use these calculations to determine how likely the observed difference between experimental conditions is when only chance factors were operational.

The recurrence of the term 'chance' emphasizes that the basic rationale of statistics is founded on calculations that are based on the assumption that all measurements in an experiment are determined by chance. Hence, even though the ultimate goal of statistical testing is to assess whether the experimental outcome (difference between conditions) is theoretically important, the starting point is that it is only one of the many possible differences that can occur when no such theoretical difference is involved. At first sight, this is a strange logic: in order to try to prove that, for instance, two conditions are theoretically different, assume first that there is no real difference between them (metaphorically, they are the same 'coin') and that the observed numerical difference is nothing more than a mere chance effect. This starting point is known as the *null hypothesis:* the conditions that are compared in the experiment do not differ from each other.

Note that, by following this line of reasoning, one can make calculations in the world of mathematics and easily calculate the occurrence probability of each possible difference between conditions. However, an experiment is obviously about the real world. So, the pressing question is: how can one 'escape' from the world of mathemetics to make a statement pertaining to the real world? In other words, how can one make the step from the assumption that the observed experimental difference can always arise under chance conditions (according to the laws of probability theory), even when there is nothing to be found at the theoretical level, to the conclusion that this outcome is meaningful for the researcher's theory (or not)? The answer is that, strictly speaking, one cannot!

The calculations behind a statistical test, which are mathematical, can only follow the path of logic described above. When two conditions A and B can contain numbers between x and y (lower and upper limit of the possible observations; e.g., 0 to 2500 ms in a reaction time experiment, 0 corresponding to an accidental button press at the time of stimulus onset and 2500 ms corresponding to an experimenter-set time-out), it is possible to generate all theoretically possible series of numbers in A and B for a given sample size (say 20 'participants') and combine all possibilities for A with all possibilities for B. This will obviously result in a huge set of mathematically possible 'outcomes' for A and B, given the available numbers. Given this, it is possible to determine the means for A and B for each outcome, calculate their difference, and finally calculate the probability to observe this difference within the set of all possible outcomes. In other words, the only thing that a statistical test can calculate is how likely it is to observe a difference ... *if there is no theoretically relevant difference between the conditions and the difference is only the numerical outcome of chance.* This amounts to determining the probability that the null hypothesis is true.

3.2.2 *Calling a result statistically significant is taking a calculated risk*

So, strictly speaking, each possible numerical difference is compatible with this null hypothesis and there really is no 'bridge' between the world of mathematics and the empirical world, i.e., the home of an experimenter who wants to know whether the measured difference indicates a theoretically relevant distinction or not. It is obvious that a researcher cannot be satisfied with such a situation and wants to make a decision with respect to the research hypothesis. There is only one way to accomplish this: through a leap of faith. As any leap of faith, this involves risk-taking, but it is a calculated risk. A researcher decides that a difference between conditions A and B is theoretically relevant when its occurrence probability in the entire set of all possible outcomes is very small when only chance were at work.

The reasoning can be paraphrased as follows: "When the probability of finding this difference or a more extreme one by pure chance is so small, I can safely ignore this probability, reject the null hypothesis stating that this is a chance effect, and *decide* that the difference was caused by my own manipulation of the independent variable, which shows this variable to be theoretical important". Note that this is a decision that inevitably involves the risk of making an error, a risk that can be quantified because it equals the probability at which the researcher decides that an outcome is theoretically important. The technical term for a theoretically important result is a *significant result.* As has become clear now, statistical significance is associated with risk and the *possibility of erroneous decision making.* Without accepting that, experimental science is impossible!

The probability marking the threshold below which a difference is called significant (the so-called alpha level) differs between sciences. Experimentalists in the humanities and social sciences (psycholinguists, experimental psychologists, researchers in pedagogical science) adopt .05 as their cut-off point, which means that they call an experimental effect significant when it would occur in 5% or fewer occasions when only chance factors were at play. Note that this means that in 1 case out of 20, they will call an effect significant when it is in fact a chance effect. This might seem a relatively tolerant cut-off value. However, there are reasons to adopt it. Indeed, the data are produced by people, whose attention fluctuates from moment to moment (fatigue, distraction, ...), such that the measurements are considerably more contaminated by irrelevant 'noise' than in the case of more exact disciplines like, for instance, pharmacology, where biochemical effects are measured (e.g., the effect of a pill). In such domains a significance threshold of .001 of even less is adopted, which means that, in order to be significant, the observed difference in an experiment shoud have an associated *p* value of .001 or less, indicating that this outcome would occur by chance in only 1 case or less per thousand trials. Stringent alpha levels are also adopted when the risk of making the wrong decision is costly, both in financial and human terms. For instance, when assessing the benefits of a new, potentially dangerous medication, one should minimize the risk of drawing the wrong conclusion. This means that one should be reluctant in accepting the experimental effect as a true effect and be strongly inclined to consider it as a chance effect (hence: alpha value is set at 0.001 or less).

3.2.3 *Main effects and interaction effects*

Depending on the number of independent variables in the experimental design one can assess the statistical significance of different effects. If there is only one such variable one can obviously only find out whether the different conditions on this variable behave differently. This amounts to testing the significance of the so-called *main effect* of the variable. This effect can always be calculated, whether there are two, three or more conditions on the independent variable. Note that a significant *p* value does not mean that all conditions differ from each other; it means that not all conditions are (sufficiently) equal, i.e., at least one condition behaves differently, and that the chance of finding these data by pure chance is very small. Hence, a statistically significant main effect of, for instance, the factor Age in an experiment with, say, three conditions indicates that the effect of age on the factor that is measured (dependent variable) is not the same for the three groups. In order to find out which conditions differ from each other, one has to perform so-called *pairwise comparisons,* in which two conditions are compared at a time.

In designs involving two or more independent variables one can test the statistical significance of two types of effects: the main effect of each variable and the *interaction effect* between the variables. In our previous example where the existence of prelexical morphological decomposition was investigated in an orthogonal design, crossing the factors Prime Type (critical vs control) and Target Type (target embedded in a true derivation, a pseudo-derivation, or in a word lacking the orthographic pattern of a suffix) one can test the following effects: the main effect of Prime Type, the main effect of Target Type, and the so-called Prime Type by Target Type interaction. The first main effect indicates whether responses are faster when the target is embedded in the prime, irrespective of the type of target (i.e., collapsing across the conditions of the Target Type factor). The second main effect indicates whether there are significant differences in the response speed to words in the three Target Types, irrespective of whether a critical or control prime is used (i.e., collapsing across the conditions of the Prime Type factor). Finally, the interaction effect indicates whether the effect of the factor Prime Type is the same within all conditions of the factor Target Type. When the effect of a critical prime is sufficiently different in one Target Type condition than in the others, the interaction effect will be significant. This will require so-called post hoc analyses of the effect to find out which pairs of conditions differ from each other with respect to the effect of Prime Type. An interaction effect between two design factors is the simplest interaction possible.

In more complex designs, involving three or even more independent variables, there are many interaction effects. Suppose one ran the experiment on blind morphological decomposition with the extra variable Language by running it simultaneously in English, French, and Dutch (orthogonally crossing Prime Type, Target Type, and Language). Then one could assess the so-called *three-way interaction* between the three variables and the three possible *two-way interactions* between two independent variables (collapsing across the conditions of the third variable). A significant interaction of Language by Prime Type by Target Type would indicate that the pattern of priming effects for each of the three Target Type conditions varies as a function of the language in which the experiment is run. In that case the design would have to be broken up and an analysis of the Prime Type by Target Type interaction be performed for each language separately. When the two-way interaction between, for instance, Prime Type and Target Type is significant (collapsing across the three languages), this would mean that the effect of a critical prime differs depending on whether the target occurs in word-initial position of a true derivation, a pseudo-derivation, or a word that does not end with the orthographic pattern of a suffix.

Note that the latter two-way interaction can be significant, irrespective of the significance of the three-way interaction. When both are significant it means that the priming patterns across the three target types differ across the three languages but that these patterns in one or two languages show a strong (and consistent) pattern, which gives rise to an overall significant interaction between Prime Type and Target Type when collapsing across the three languages. Suppose the following (imaginary!) set of priming effects for derivations, pseudo-derivations and orthographic controls, respectively, for each language: English (35-31-12), French (37-33-10), Dutch (33-29-32). These effects would be compatible with a third-order interaction, Dutch being the odd-one out. However, when averaging across the three languages in order to test the Prime-Type by Target Type interaction, the pattern of priming effects would be: 35-31-18, which could reflect a two-way interaction, the orthographic control condition being the odd-one out. This means that the small priming effects on words like *sand* (embedded in *sandal*) are so consistent in two of the three languages that the language lacking this pattern (Dutch) cannot neutralize this. The fact that this overall pattern reflects the impact of only two of the three languages is indicated by the third-order interaction.

As mentioned above, it is also possible that the Prime Type by Target Type interaction is significant but the third-order interaction is not. This indicates that the pattern of priming effects differs significantly across the three target types (two-way interaction) and, moreover, that this pattern is basically the same in the three languages (absence of significant three-way interaction).

These considerations can be generalized to designs with more than three independent variables, as the same logic applies irrespective of the number of variables involved. Note, however, that experimenters should not attempt to build experimental designs that contain too many variables and that not too many conditions per variable should be included in the design. Complex designs tend to have too few observations per design cell and give rise to so many interactions that it is often difficult to understand what the data tell. Small experiments with two or three independent variables and relatively few conditions per variable are the most elegant and best interpretable ones. It is striking to observe that the best experiments in the literature, whose results survive time and the fashion of the day, are often based on such elegant designs.

3.3 Statistical tests

Once one has collected the experimental data, one must choose a test to analyze them, i.e., assess the significance of the main and interaction effects. It is far beyond the scope of this chapter to discuss al possible tests and how to decide which one to choose. However, I will introduce the most fundamental issues involved and briefly discuss some statistical tests because of their frequent use in empirical studies of language (not necessarily experimental studies).

3.3.1 *Types of measurement scales*

The most important criterium for choosing the proper test is to be aware of the measurement scale used to collect the data. There are four such scale types. A *nominal* scale implies that one counts how many units in an experiment possess a certain property (e.g., number of males vs females, number of students who pass or fail, number or errors of type x vs number of errors of type y). An *ordinal* scale implies that one determines the position of each unit on a rank-ordered scale, where each number on the scale corresponds to a particular degree of a certain property. However, distances between any two successive ranks do not correspond to an equal difference. For instance, one can divide dimensions like 'degree of musical talent', 'willpower', 'semantic transparency of a compound word' in a number of regions on a 5-point scale, but the difference between values 2 and 3 need not (and often will not) correspond to the difference between vaues 4 and 5. This is because the scale values are not real numbers but only labels for degrees of a certain quality. Few people can divide their subjective assessments in equally-sized psychological distances, which directly map onto the labels of the scale. An *interval* scale refers to measurements on a scale where the difference between two successive points is a constant but where there is no absolute zero point (e.g., the difference between IQ scores). Finally, a *ratio* scale is a measurement scale where the difference between any two successive points is a constant and which has a definite zero point (e.g., weight, length, reaction time). As the name of the scale implies, these scales allow one to make ratios between measurements (e.g., 40 kg relates to 20 kg like 10 kg relates to 5 kg, i.e., the former object is twice as heavy; 1200 ms relates to 400 ms like 900 ms to 300 ms, i.e., the former duration is three times longer).

The large set of statistical tests can be sorted under two general headers: parametric and non-parametric statistics. Rougly speaking, data that have been collected on a nominal or ordinal scale require a non-parametric test, whereas measurements on interval and ratio scales require the use of a parametric test. I will discuss each test type in turn and briefly enter into a short discussion of the most commonly used tests for each type.

3.3.2 *Non-parametric statistics*

3.3.2.1 *The chi-square test*

Probably, the best-known non-parametric test is the chi-square test. This test can be applied to designs using one or two independent variables. Suppose a company wants to determine which soft drink people prefer (A or B), so as to be able to make an informed decision about the required production of both types of drink. The company offers both drinks to 200 people and asks them to say which one they prefer. The outcome is that 82 people prefer drink A and 118 drink B. Is this difference statistically significant, i.e., large enough to support a decision to produce more of drink B?

As mentioned earlier, the question is to calculate the likelihood of the observed outcome starting from the hypothesis that there really is no preference for either type of drink and that the difference is a pure effect of chance. The chi square test calculates a number (the chi square statistic) that can be mapped onto the likelihood that this is a pure chance outcome, the so-called *p* value (where *p* stand for probability). This is the logic behind the mathematics. Let us now have a brief look at how the test arrives at its *p* value.

A pure chance distribution of the 200 people over drinks A and B would be 100–100. It is almost certain that this distribution will not be observed, as there are more theoretical possibilities to break up a sum of 200 in two different numbers than in twice the same number, also through the effect of chance. However, as argued in Section 3.2.1.1, the issue is not whether there *is* a difference but to determine *how likely* the magnitude of this difference is with respect to all possible differences.

The chi-square test basically consists of the following steps: (i) an estimation of the expected (E) values if only chance had played a role, (ii) a quantification of the divergence between the observed (O) and E values for the different conditions, which leads to the value of the χ^2 statistic and (iii) the determination of the likelihood of obtaining this magnitude of divergence if the null hypothesis were true, i.e., if only chance had played a role (incidentally, this would be the case if the same drink were presented in conditions A and B, so that any difference between A and B could not be the result of the type of drink).

To find an index of divergence, a reasonable start seems to be the calculation of the difference beween the actual and expected number for each design cell: O-E. One might then be inclined to think that summing these divergences across the design cells will give an estimate of the overall divergence in the matrix. However, as the sum of all observed values and all expected values must necessarily be identical, the sum of negative differences will always be exactly the opposite of the sum of positive differences (irrespective of the number of conditions), with the result that this index of divergence will always sum to zero. With a little mathematical trick this problem can be circumvented by squaring the differences: $(O-E)^2$. Now that only positive numbers are left, we must bring back the quadratic scale to the type of scale we set out from. For that reason, each squared difference is divided by the expected value for its own design cell. Thus, for each cell, we express the divergence as a ratio, more particularly, a ratio indicating how many times the squared divergence between observed and expected values exceeds the expected value: $(O-E)^2/E$. When summing across there ratios across all design cells of the matrix, one obtains the value of the chi square statistic. So, the formula for chi-square is:

$$\text{(i)} \quad \chi^2 = \Sigma^{n}_{i=1} \frac{(O_i - E_i)^2}{E_i}$$

Applying formula (i) to the example with drinks A and B results in χ^2=6.48. The *p* value that is associated with this chi square value can be calculated from a function that maps χ^2 values on the x axis onto *p* values on the y axis. In Excel there is such a function, *chidist,* which returns the p value when it is given the value of two parameters: χ^2 and the degrees of freedom (df) in the matrix. I will not digress on the latter technical concept. The df for an independent variable equal the number of conditions minus 1. For instance, in the example with drinks A and B, there is only 1 df. In an orthogonal 2×3 design the first variable would have 1 df, the second would have 2 df, and so the design would have 1×2 or 2 df. Entering the value of χ^2 and the df in the chidist formula gives a *p* value of 0.01, which means that the difference is significant and, hence, not likely to be the product of chance differences in the participants' choices. Accordingly, the company has a statistical reason for producing more of drink B than of drink A.

In order to calculate the *p* value for a chi square test one can, of course, also make use of a familiar software package or an internet site containing an applet that automatically calculates the *p* value. One can even use another function in Excel, *chitest,* which outputs the *p* value when you enter the observed and expected values (note that this function does not return the value of χ^2 itself).

An important remark: the expected values do not always correspond to the total number of observations divided by the number of conditions. For instance, it is not necessarily the case that when you make 300 observations overall and study three conditions, your E values will be 100 for each cell. Consider a concrete example. Suppose that one wants to compare one specific kind of spelling error in the spelling of two word types in a corpus of texts. Word Type 1 gives rise to 86 errors whereas Word Type 2 gives rise to 94 errors.

At first sight, this is such a small difference that it seems highy unlikely to be significant. However, it would be a large mistake to add the values for these two error types (180) and to calculate the expected values by dividing this sum by two (90). One should only follow this practice if the corpus contains the same number of words from both types. More likely, however, corpora tend to contain unequal numbers of tokens for different conditions.

Suppose, for the sake of exposition, that 533 words in the corpus belong to Word Type 1 and 900 to Word Type 2. This means that the corpus contains a total of 1,433 words on which an error of the expected type can be made but that there are many more opportunities for making an error on Word Type 2, more particularly, 900/1433 or 63%. Obviously, this higher *a priori* error risk should be reflected in the expected values. If the total number of errors (180) were distributed in a pure chance fashion over the two word types, the proportion of error occasions in the corpus should be calculated for each Word Type (533/1433 for Word Type 1 and 900/1433 for Word Type 2) and these proportions should be applied to the total number of observed errors in order to obtain the expected values. In other words, the latter values are obtained by making the following calculations: 180*533/1433=67 for Word Type 1 and 180*900/1433=113 for Word Type 2. The divergence between the observed and expected values for Word Type 1 (86 vs 67) and Word Type 2 (94 vs 113) yields a χ^2 of 8.63 and an associated p value of 0.003, which is highly significant. Hence, two observed values can be almost identical and yet differ significantly because there are more observation possibilities in one design cell than in the other.

The chi-square test is often used for designs with two orthogonal independent variables. For instance, a researcher who is interested in the frequency with which two lexical or syntactic variants occur in the spontaneous speech of, say, teenagers between fourteen and eighteen in three dialectal regions could come up with the counts in Table 2.

Table 2. Frequencies of two linguistic variants in three geographical regions

	Variant 1	*Variant 2*	*ROW TOTAL*
Region 1	42	33	**75**
Region 2	66	87	**153**
Region 3	54	29	**83**
COLUMN TOTAL	**162**	**149**	**311**

The researcher can use these data to answer two questions. Is there a preferred usage for either variant, independently of region? Does the choice between the two variants vary among the three regions? To answer the first question, the frequencies have to be calculated across regions and a simple χ^2-test can be performed on these two sums. The answer to the second question requires that a χ^2-test determines whether in each region the total number of observations is similarly distributed over the two variants. The formula for calculating the chi-square statistic is (obviously) the same: divide the squared difference between the observed and expected values by the expected value and sum across design cells. The mathematical logic behind the calculation of the expected values is similar to the above example with a single independent variable and unequal observation possibilities for the different conditions. If the division of observations between the two variants is independent of the region where they were collected, then the proportion of observations obtained for each variant in the total number of collected data (summed across regions) is expected to recur in each region. For instance, the ratio 162/311 for Variant 1 (column total) is expected in Region 1, such that 162/311*75=39, in Region 2, where application of this ratio to the 153 observations yields an expected value of 80, and in Region 3, where the same calculation yields 43. Similarly, application of the ratio 149/311 for Variant 2 to the region totals 75, 153 and 83, yields expected values of 36, 73 and 40. Entering the observed and expected values in the chi-square formula yields $\chi^2=10.97$, $p=.004$, which is a highly significant interaction between the variables Region and Variant. At the theoretical level this means that the preference for one linguistic variant over another considerably depends on the region.

3.3.2.2 *The Wilcoxon and Mann-Whitney test*

A test that we will review very quickly for data on an ordinal scale is the Wilcoxon test. When a number of observations in two conditions are made on such a scale one can rank order the observations from small to large, replace each observation by the name of its condition (say, A and B), and then assign a rank to that observation in that condition. The essence of the Wilcoxon test is that, when the observations in the two conditions are distributed by chance only, one expects that the two conditions will show a similar distribution across the rank-ordered sequence (a similar number of A's on the left side as on the right side of the sequence, the same for the B's) and that the sum of their respective ranks will be roughly the same. However, if one condition is systematically associated with lower scores (more A's on the right side than on the left one, hence, lower ranks in the rank-ordered sequence) than the other, one expects a lower sum of ranks for that condition. The Wilcoxon test makes use of these sums of ranks to calculate a statistic, which is then mapped onto a p value. The test exists for both so-called paired observations, which means a within-participants or within-items manipulation has been used, and for so-called independent samples, i.e., two sets of independent participants or items. In its version for independent samples it is equivalent to the Mann-Whitney test, which is perhaps better known. Again, statistical software packages and applets on the internet offer opportunities for quickly running these tests on one's data.

3.3.3 *Parametric statistics*

3.3.3.1 *Some general remarks*

Lets now turn to the class of parametric tests. A parametric test makes two important requirements. The first is that the data be collected on an interval or ratio scale, i.e., that the difference between any two consecutive numbers has the same magnitude. This is, for instance, not the case with 'numbers' on an ordinal scale: the difference between a preference of 3 and 4 when rating the taste of a drink on a 7-point scale is probably not the same as the difference between 5 and 6, and will moreover not be equal for each person in the experiment. The numbers on such a scale are not true mathematical numbers, only numerical labels that could readily be replaced by verbal labels like, in the case of a taste judgment 'very bad', 'fairly bad', 'neutral', 'fairly good', 'very good', etc.

The second requirement regards the nature of the data distribution in the entire population. This is technical language but just means that the sample of data that has been collected in the experiment is drawn from a data set of all theoretically possible observations (hence, the population) and that this population must have a particular distribution. The two parametric tests that are most often applied in language research, the t-test and the analysis of variance (ANOVA), both hinge on the assumption that the experimental data come from a population with a normal distribution, which is the well-known bell-shaped distribution that also goes by the name of the Gaussian distribution.

Another contrast with tests like the chi-square test is that the data in each condition are not collapsed across all participants and/or language items used in the experiment. Rather, participants or items are entered as a variable themselves, such that each participant/item has a separate data point in one or several conditions. As a result, these tests can make more reliable statements with respect to the experimental hypothesis. Supppose that in our example on the use of two language variants in three regions the researcher is suddenly struck by the fact that in Region 2, which contrasts with the other two regions because it is the only region where Variant 2 is preferred to Variant 1, the 87 observations of Variant 2 are mainly caused by two participants. These participants were the only ones who never used Variant 1 and it turns out that removing them from the data seriously affects the data pattern for Region 2, which changes into 66 vs 57 occurrences for Variants 1 and 2, respectively. The result is that the interaction between Region and Language Variant is no longer significant: χ^2=2.75, p=.25. The cause of the problem is obvious: collapsing the data across participants implies that possible differences among them are ignored and, hence, entails the risk that the observed frequencies are heavily skewed by participants with extreme values. In such a situation, the researcher will draw the wrong conclusion, as his conclusion will not apply to the average person from the population under study. Needless to say, the ultimate purpose of any experiment is to arrive at just such general statements.

Parametric tests avoid this trap by explicitly calculating whether the difference in means between conditions can be generalized to the population of participants or to the population of items. However, these tests can go seriously wrong if the assumptions about the population distribution are violated. This is because a test on data that are drawn from a normal distribution is founded on the known mathematical properties of such a distribution, for instance, the fact that 95% of the data fall within 1.96 standard deviations from the population mean. This means that if you determine the standard deviation of all data points from their mean and add it 1.96 times to the population mean you can be sure that the number of more extreme data on that side of the curve corresponds to 2.5%. Equally, when you subtract 1.96

standard deviations from the mean, there are still 2.5% more extreme data left on that side of the curve. It is not an accident that this total of 5% corresponds with the alpha level of .05 that is used as a cut-off point for statistical significance in the humanities and social sciences. The alpha level of .05 is based on these mathematical properties of the normal distribution.

It would be nice if these mathematical properties of the normal distribution could be applied to the outcome of a statistical test itself. Suppose that the outcome of a statistical test expressed, for instance, the number of standard deviations that a particular measure of the experimental results deviates from the mean of all possible values of this measure. Suppose further that these values are normally distributed. In that case, the value of the statistical test would be very easily interpretable. For instance, a value of 1.96 would mean that the value of the intended measure of the experimental outcome deviates 1.96 standard deviations from the mean of its population, which, given the normal distribution, would mean that it corresponds with a p value of .05. Although the foregoing description comes close to what the t-test does (see below), the description is an idealization. As a matter of fact, each statistical test does not have one but many distributions, depending on the degrees of freedom (that technical term again!). In the case of the measure described above, there would be a slightly different distribution for each sample size. Importantly, none of these distributions would be a normal distribution. Only when the sample size approximates infinity would the form of the distribution approximate the form of the normal distribution.

3.3.3.2 *The student's t-test*

General aspects

The t-test is a very frequently used test for an experimental design in which two conditions on a single independent variable are compared (Student was the pen name of William Gosset, a chemist who invented the test). For instance, a researcher might want to find out whether teenagers perform better on a verbal memory test when they study on a computer than in their textbook. The test includes five vocabulary tests, each time involving the study of 20 foreign language words and their translations (total score=100). Lets say that two groups of 31 students each participate in the experiment and are given equal study time. The textbook group can work according to their preferred study method whereas the computer group is presented the items one after the other in a randomized order and is represented the items for which they gave a wrong translation. One hour after studying the words, all participants receive a paper and pencil test on which they have to translate all foreign words into their native language. Suppose the mean score on the test is 72 for the computer group and 65 for the textbook group. Is this difference statistically significant, such that the conclusion is warranted that studying foreign language vocabulary on a computer is superior to studying it by means of the classical textbook method?

In line with what has been said in Section 3.2.1.1, one would want to be able to have access to all theoretically possible mean scores that each group can obtain on the basis of pure chance. The ideal would be that one could infinitely many times repeat the following procedure: (i) assign a randomly drawn score between 0 and 100, i.e., the population of possible scores, to each of 31 'students' in two groups, (ii) calculate the means of these two randomly generated number sets, (iii) determine their difference score and (iv) calculate the occurrence probability of each difference score. Theoreticaly, all difference scores between +100 and −100 are possible, i.e., all participants in the computer condition obtaining the maximum and all participants in the textbook group obtaining zero, or vice versa, but obviously the odds of observing such extreme differences are very small.

In the simulation below we will, for the sake of simplicity, randomly draw the score of each 'participant' from a normally distributed population of natural numbers whose mean equals 50 (maximum=100) and whose standard deviation is 20, which means that about 95% of all scores fall between 11 and 89 (mean ± 1.96 standard deviations). Figure 1 visualizes the outcome of a simulation of one million runs of the procedure described above, representing all observed differences between the two means on the x-axis and their associated occurrence frequency on the y-axis. Note that a simulation of this kind is necessarily incomplete and only approximates reality, as it is based on 'only' one million pairs of random samples whereas the true statistical test must be calculated with respect to the distribution that is derived from an infinite sampling procedure (whose properties can, of course, only be estimated through mathematical techniques).

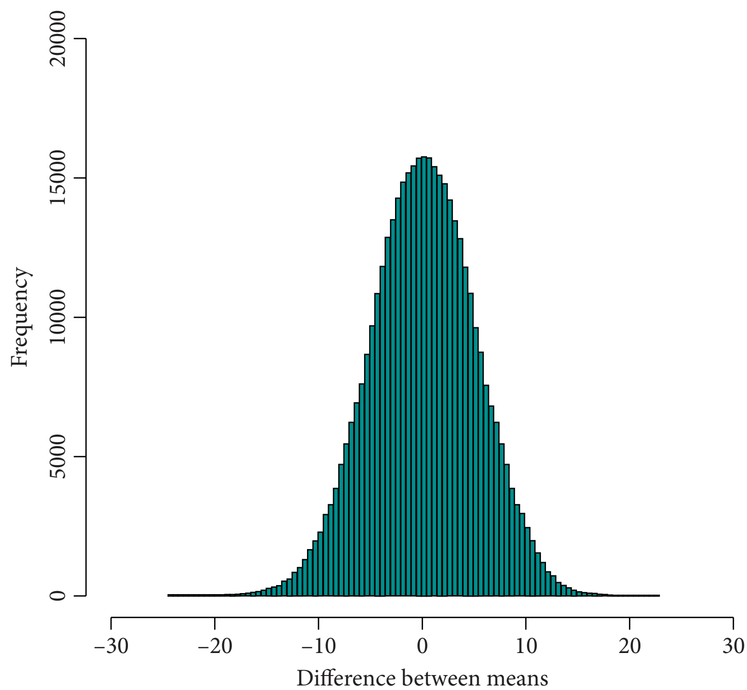


Figure 1. Frequencies for the differences between the means of two sets of 31 randomly generated numbers from a normal distribution with mean 50 and standard deviation 20. The plot is based on one million runs

If one had access to information like the figure above (for the entire, infinitely large population) one could directly calculate the probability of finding the observed difference between the two means in the experiment. As the mean of the population of differences is virtually zero and the standard deviation 5.08, the cut-off points for the .05 level of statistical significance can be calculated. These correspond to the values, to the left and to the right of the mean (depending on which condition has the highest score), that are 1.96 standard deviations removed from the mean. It follows that any difference between the two means that falls beyond these values, falls within a region of observations whose summed occurrence frequency represents 5% of all observations, i.e., a proportion of .05.

So, in our comparison between learning vocabulary with the help of the computer or the classical textbook method, a difference will only be significant at the .05 level when it is removed more than 1.96 times the standard deviation of 5.08 from a mean of zero, i.e., the critical difference is 9.96. As the difference between the observed scores of 72 (computer condition) and 65 (textbook condition) equals 7, it follows that the experimental outcome is not significant. Hence, despite a trend towards an advantage in the computer-assisted condition, the difference with respect to the textbook method is not large enough to be significant, i.e., it could occur too often on the basis of pure chance.

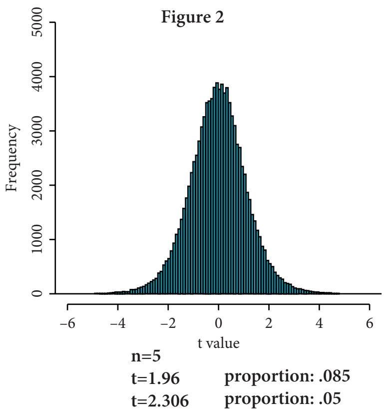
As said, this is not how one actually determines whether a difference between two conditions is statistically significant or not, although the statistical test itself (the t test) is based on exactly the same logic as the one described above. The only difference with the simulation is that statisticians have discovered techniques for estimating the mean and the standard deviation of the non-observable population consisting of the infinite set of all possible difference scores (mean A minus mean B), more particularly, on the basis of properties of the sample studied in the experiment. More concretely, a t-test is a ratio in which the nominator is the observed difference between the two conditions in the actual experiment and the denominator is an estimate of the standard deviation of all possible differences between two random samples with the same size as the one used in the experiment. This standard deviation in the distribution of differences is technically called the standard error and is estimated from both the standard deviation in the two experimental samples and the two sample sizes. When formulated in human language, a t value simply expresses how many standard deviations the observed difference between the two means in the experiment is removed from the mean difference score in a population (i.e., the standard error of the difference), more particularly, the population of all possible difference scores that can be derived from samples with the same sizes as those used in the actual experiment (the so called sampling distribution).

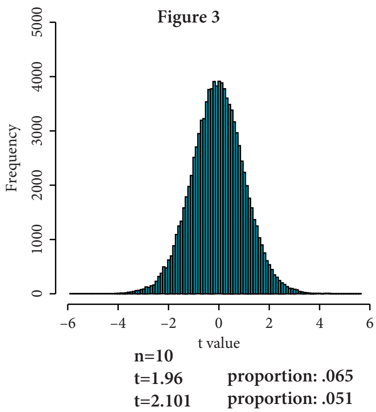
In a perfectly normal distribution a deviation of 1.96 standard deviations corresponds to the significance level of .05. Would this be the case here as well, i.e., would the t-test be significant at the .05 level when $t=1.96$? No, as mentioned above, the critical value of t at which the associated p reaches the critical .05 threshold depends on the sample size. The size of the two samples that are used to calculate the condition means are parameters when estimating the standard deviation in the sampling distribution of all possible differences between conditions A and B. Note that this mathematical fact corresponds with common intuition: if you want to estimate the standard deviation in the length of, say, all men between 20 and 30 in a particular country, the standard deviation in your sample will be a much better approximation of the population standard deviation when the sample contains measurements for 1000 men than only for 50 men. Hence, the larger the samples that are used for the two conditions, the closer the value of t that is required to obtain significance approximates the value of 1.96, i.e., the point beyond which 5% of all observations are to be found (summing across negative and positive differences).

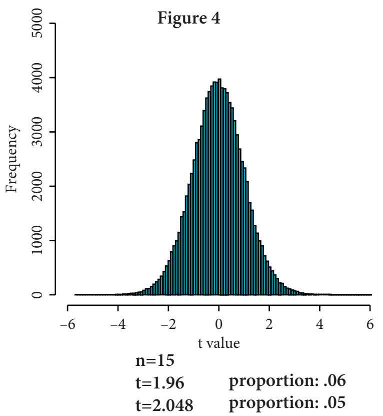
Figures 2–6 below make this more tangible. For each of five different sample sizes (n=5, 10, 15, 21, and 61) a simulation of 100,000 runs has been made and a t value has been calculated on each run. The purpose of each simulation is to find out how the values of t are distributed when two samples of size n are randomly drawn from a single normal distribution, i.e., when pure chance is at work. For this purpose, two such samples were randomly drawn from a normal distribution with a mean of 50 and a standard deviation of 15 (lets say, the marks obtained on a language exam, marked on 100). Then the value of t was calculated by dividing the difference between the two sample means by an estimate of the standard deviation of all possible difference scores, based on the standard deviation in the samples and the sample size. For each of the five values a calculation was made which proportion of t values out of 100,000 falls at or beyond ±1.96 (.05 in a perfectly normal distribution) and which t value corresponded to the cut-off point where only a proportion of .05 represents t values as extreme as ±1.96. The latter cut-off points for t come from a statistical table but the proportions are the values observed in the 100,000 runs simulations. As one can readily see, as sample size increases the value at which t becomes significant comes closer to the value of the normal distribution, i.e., ±1.96. When the sample size approximates infinity, t=±1.96 will have a p value of .05.

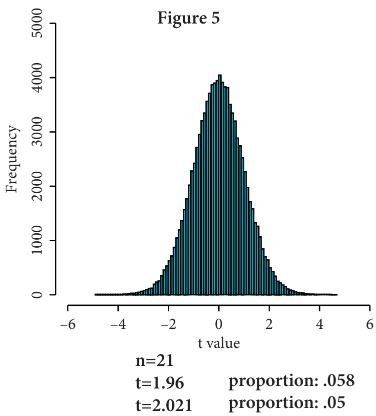
Paired versus independent observations

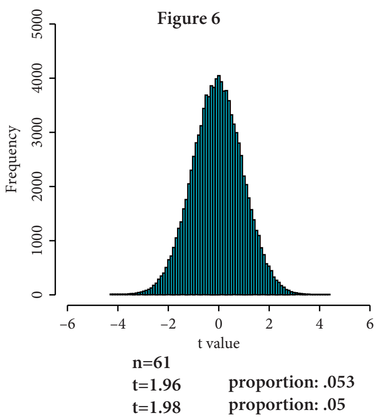
When doing a t test, one has to be aware of the importance of two additional distinctions, both of which affect the statistical significance of the outcome. The first is whether the manipulation of the independent variable was within participants (or within items), giving rise to *paired observations* for the same participant (item), or between participants (between items), giving rise to *independent observations.* Whenever a between-manipulation is not required by the nature of the research, a within-manipulation should be preferred, for the simple reason that statistical significance is obtained more readily with the latter kind of manipulation, i.e., the same difference can be significant in a within-participants (items) design but non-significant in a between-items design.











Figures 2–6. The distribution of t values together with their occurrence frequency for samples of different size, each time representing 100,000 runs. Under each figure, three pieces of information are provided: (i) the sample size, (ii) the proportion of t-values with a more extreme value than ±1.96, i.e., the value in the normal distribution beyond which only 5% of the values is situated, and (iii) the value t at which a proportion of .05 values is more extreme, i.e., the point at which t becomes significant. The larger the sample becomes the more (iii) begins to resemble (ii)

It is easy to understand why. The t test estimates the standard deviation in the population of all difference scores on the basis of a formula in which the difference between the two condition means is divided by the standard deviation estimated from the sample and is furthermore a function of a second term involving sample size. Simplifying somewhat by just focusing on the standard deviation from the two samples (the term involving sample size even further increases the difference), it soon becomes clear why observations from the same participants (items), give rise to a smaller denominator and, hence, a larger t value than observations that have been collected in independent samples of participants (items). First, since pairs of observations are made on single participants or items, these observations can be subtracted from each other, such that two sets of scores can be transformed into one set of difference scores. Such a participant-by-participant (or item-by-item) difference is impossible in a between-participants (items) design, as there are no repeated measures. Second, since the variability in two sets of data collected from the same participants (items) tends to be strongly correlated, in the sense that the best performers will generally be the same in the two conditions, there will be less variability in this single set of differences scores in an experiment with paired observations than across all data in a between-participants (items) design. This will be reflected in a smaller standard deviation in a design with paired observations. In other words, for the same data set, the t value will be larger for a design with paired observations than for a design with independent observations.

However, the use of paired observations at the same time decreases the sample size. If there are 20 observations in each condition, the sample size is 20 in the case of a within-participants design but 40 in a between-participants design. As large samples provide more information for estimating properties of the population they are drawn from, in this case the population of all possible differences between sample means, the advantage of paired observations is to some extent reduced by the resulting differences in sample size. However, the combined effect of these two factors is strongly in the advantage of a within-participants (items) design, i.e., paired observations.

In a simulation of 100,000 runs, two sets of 15 observations each were drawn from a population with mean 50 and standard deviation 20. To simulate the correlation between sets of paired observations, the data in the first sample were multiplied with a factor 1.5 to determine the second sample (such a perfect correlation will not occur in reality, but this is just an idealized example to make the point). On each run, both a t-test for dependent (paired observations) and independent samples was performed and a counter was incremented each time the p value associated with the t-test for paired observations was smaller. It turned out that this was the case in all 100,000 runs, which clearly shows the strong advantage of a within-participants (items) manipulation.

One-tailed versus two-tailed t-tests

The second distinction that needs to be made is that between a *one-tailed* and a *two-tailed* test. Thus far I have only discussed two-tailed testing. The outcome of a two-tailed t-test can be paraphrased as follows: "The absolute value of t indicates two cut-off points, one on each side of the t distribution. It expresses the distance between these cut-off points and the mean of all possible difference scores between two samples, more particularly, in terms of the standard deviation of this population. This t value has an associated p value, which quantifies the summed proportions of the area under the t curve between each cut-off point and more extreme values on that side of the curve". The motivation for two-tailed testing is that in many types of research it is not possible to say whether condion A will outperform condition B or vice versa, i.e., the difference between the condition means can both be positive or negative. However, if one has very good theoretical reasons that the hypothesis only makes sense when it is formulated in a directional way, one can rely on one-tailed testing. For instance, the hypothesis that rehearsing foreign language vocabulary daily will cause better performance on vocabulary tests than rehearsing it only twice a week seems to leave little room for better performance in the twice-a-week condition.

The distinction has again direct repercussions for the significance of the t-test. In a two-tailed t-test a t value that is associated with p=.05, 2.5% of the possible t values on both sides of the curve are more extreme. In a one-tailed t-test where the t statistic is associated with p=.05, only one side of the curve is inspected (e.g., the side with positive differences, given the directional nature of the hypothesis). In this case, all 5% of the more extreme t values are situated on the same side of the curve. The implication is immediately obvious: when using one-tailed testing, a smaller t value is required to obtain the same level of significance. In order to obtain p=.05 in a two-tailed testing situation one has to 'cut off' 2.5% of the area under the curve on both sides of the t distribution. Since, one can cut off all 5% of the area on a single side of the curve in a one-tailed testing situation, the threshold at which t becomes significant moves towards the centre of the curve, such that a smaller t value reaches significance.

3.3.3.3 *Analysis of Variance (ANOVA)*

I will only briefly discuss the essence of a widely used test in experimental research: the analysis of variance, generally abbreviated as ANOVA. The ANOVA has a much broader range of application than the t-test. Whereas a t-test is restricted to a design comparing two conditions on a single independent variable ANOVAs are suited for designs in which two or more conditions on a single or different design variables are distinguished. Its output is the significance of each independent variable in the design and all possible interactions between the design variables.

The rationale behind the test is easy to follow when it is explained on the basis of a simple design, for instance, one where only three conditions on a single independent variable are compared. The test sets out from the obvious observation that all data in an experiment are distributed across the dependent variable (measurement factor) and that the variability within the data can be conceptualized as the result of different 'forces' exerted on the grand mean of the experiment. Suppose that one tests three groups of 20 participants on their recognition speed for three sets of 30 words each: high-frequency, medium-frequency, and low-frequency words. The words in the three conditions are matched on letter length and concreteness and the manipulation is between-participants (not a good idea, but this is just for the sake of exposition). Suppose further that we analyze the participant means, i.e., the means obtained in each condition by averaging across the reaction times for all items. These participant means are distributed across the reaction time scale and are scattered around an overall, grand mean.

The ANOVA sets out from the assumption that each condition of an independent variable has a constant effect on the dependent variable and that there is an inherent logic in the way the data are distributed across the dependent variable. If one starts at the overall mean (grand mean) of all data points and adds the effect of the condition to which the data point belongs (e.g., the effect of high-frequency words) one has 'travelled' part of the way towards the data point, more particularly, a part that can be explained by a condition on an independent variable. The remainder of the path towards the data point is a 'distance' that is unaccountable for and that is, hence, referred to as the residual or the error. Consequently, in an ANOVA design with a single independent variable, like the one above, one can rewrite each data point as:

$$\text{(ii)} \quad X_{ij} = \mu + \alpha_i + \varepsilon$$

where X_{ij} represents data point j in condition i, μ stands for the grand mean, α_i represents the effect of condition i belonging to the independent factor A and ε represents the remaining 'distance' to the grand mean that is unaccounted for by any systematic effect. For instance, in order to 'travel' to a data point with value 327, given a grand mean of 486 and a condition mean of 350 the reasoning proceeds as follows:

$$327 = 486 + (350–486) + (327–350)$$

where 486 is μ, 350–486 is the effect of condition α_i (condition mean - grand mean) and 327–350 is the residual or error (observation in condition - condition mean).

The above equation can be rewritten as (327–486) = (350–486) + (327–350), an equation which makes quite clear that the difference between any observation and the grand mean equals the sum of a between-groups effect (or effect from an independent variable) and a within-groups effect (or error).

Since the above line of reasoning shows that each observation can be expressed as a linear combination of effects, a further step is to *partition* the entire variability that exists among the data points on the dependent variable into several parts. In the case of a single independent variable with three independent groups of participants, two sources of variability can be distinguished: (i) the *between-group variance,* which corresponds to the variance caused by the three conditions on the independent variable (the effect of α_i etc.) and (ii) the *within-group variance,* which refers to the variance caused by different response speeds among participants in each condition (the component ε).

Although the previous equation and the above line of verbal reasoning are correct, one cannot simply put the following steps to demonstrate that the total variability can be partitioned into two subparts (X_{ij} = observation, M = grand mean, A_i = effect variable A in condition i in the sample)

$$
\begin{array}{lll}
X_{ij} - M & = (A_i - M) & + (X_{ij} - A_i) \\
(327-486) & = (350-486) & + (327-350) \\
(327-486)^2 & = (350-486)^2 & + (327-350)^2
\end{array}
$$

The reader who takes the pains to work out the squares will notice that the last equation is wrong, in contrast to the equation without squares. This is also obvious. Squaring the left part of an equation requires squaring the whole right part as well. As the right part is of the form a+b and $(a+b)^2 \neq a^2 + b^2$ but $a^2 + 2ab + b^2$, the equation with squares cannot be correct. However, as there is no place to enter into the details of the mathematics behind an ANOVA here, the reader can be assured that when all these squared terms are summed across all data points, the equality will hold. In other words, it can be proved that the sum of squared distances between data points and the grand mean (henceforth, sum of squares), i.e., the total sum of squares, equals the sum of two other sums of squares: the *between-group sum of squares* (constant variability due to the independent variable) and the *within-group sum of squares* (random variability due to participant differences).

In order to determine whether the main effect of the independent variable is significant one needs to take one extra step: the division of the so-called mean square (roughly: average sum of squares) for the independent variable by the mean square for the error. In other words, the ANOVA test is a ratio reflecting how many times the variability caused by the independent variable (nominator) exceeds the variability caused by the error (error=variability that cannot be explained in terms of the experimental conditions). For this reason the ANOVA is often described as a *signal-to-noise ratio:* it expresses how strong the signal of the independent variable is with respect to the noise, i.e., the effect of the variability that is unaccounted for by the independent variable. As in all statistical tests, the same line of reasoning then follows: if the signal is so strong with respect to the noise, that a high ratio is obtained (the so-called F statistic) and that this F value is expected in less than 5% of the cases on the basis of pure chance, the difference among the conditions on the independent variable is significant. Note that a significant effect in the example with three conditions would only indicate that these three conditions differ among each other and that at least one condition behaves differently. Post hoc pairwise comparisons would be needed to find out which condition or conditions cause the significant effect.

To finish lets consider the case of the same design but with a *within-participants* manipulation of the independent variable, i.e., all participants see the three word groups. In this case, there is an extra source of variability that can be measured: that caused by the participants. The difference with respect to the between-participants design is that in the latter design there was only one observation per participant, whereas there are three now. The consequence is that in the between-participants design an observation could have reflected all possible kinds of unexplainable effects, not necessarily participant effects only, whereas now each participant has his or her own mean response time, which is supposed to isolate the participant properties from the other random effects impinging on the response times. This makes it possible for the ANOVA to assume that each participant contributes his or her own systematic effect to the data (e.g., fast or slow responses). Hence, one can now add another term to the earlier equation, one that accounts for the systematic variability among participants. So, the equation for an observation is now a function of the grand mean, a systematic condition effect, a systematic participant effect and a residual or error term:

$$\text{(iii)} \quad X_{ij} = \mu + \alpha_i + \beta_J + \varepsilon$$

The contrast between a model with a manipulation within participants versus a model with manipulation between participants, makes it clear that this choice has an immediate impact on the statistical analysis. This is not an issue of cheating, it is an issue of simple mathematics. The formulae that define the design structure make it possible or impossibe to write an equation in which the effect of participants is included, and that is a direct reflection of manipulating the independent variable between or within participants. Hence, when designing an experiment and making decisions regarding within or between manipulations, the researcher should anticipate the effect that his or her choices can have on the statistical analysis. It is important to bear in mind, at that moment, that the more sources of variability one can remove from the data, the more chances one creates for 'catching' the signal of the independent variable(s) under study – of course, if there is such an effect at all.

As this linear combination of effects makes it possible to partition the variability in the total data pattern, we will now be able to partition the total sum of squares into two sources of variability that can be accounted for, the sum of squares between conditions and the sum of squares between participants, and one source of variability that is unaccountable for, which is the remaining 'distance' between the data point and the grand mean after the effects of condition and participant have already been added. This is the error component.

One final addition: if we had a design with two independent variables and several responses per design cell there would also be an *interaction term*. An interaction is, techically speaking, the 'way one still has to travel', after having added the effect for the condition on variable A and the effect for the condition on variable B to the grand mean, in order to reach the mean of the cell where the conditions on A and B intersect. All observations made within that cell will then more or less deviate from this cell mean and will contribute to the residual error term. The equation for a two-way ANOVA (design with two independent variables) is:

$$\text{(iv)} \quad X_{ij} = \mu + \alpha_i + \beta_J + \alpha\beta_{ij} + \varepsilon$$

Whereas it is an almost impossible task to make the reader understand ANOVA analyses within a few pages of text, I hope to have made clear the most important issues. What is crucial to remember is that ANOVAs are techniques that can analyze data for more than two conditions at once and for more than one independent variable simultaneously. Additionally, their basic rationale hinges on the idea that the variability among all data points can be partitioned and that each partition can be assigned to different sources of influence, among which the independent variables in the design and their interaction (in cases where more than one independent variable is included in the design). Thus they offer a powerful technique for assessing the statistical significance of the main and interaction effects of the design variables.

3.3.3.4 *Measuring the associative strength between variables*

It often occurs that two data sets are correlated with each other. For instance, when the value on factor 1 increases the value on factor 2 increases. Such a relationship obtains, for instance, between children's age and length: the older they get, the larger they become (up to a certain age). The alternative scenario also occurs: when the value on factor 1 increases, the value on factor 2 decreases. This is, for instance, the case between word frequency and speed of word recognition: the higher the frequency of a word the shorter its recognition time.

In several forms of research it can be interesting to measure this degree of association between the two data sets. One way of doing this is to quantify this association by applying a formula. The resulting quantification expresses the *degree of correlation* between the two factors. Another way of assessing whether the two sets of values are closely related is by measuring how well the values on factor 2 can be *predicted* from the values on factor 1 (or vice versa). Hence, the goal of that method is to find a mathematical function that predicts the second value on the basis of the first. As it is virtually impossible to make exact predictions, the real goal is to find a function that generates a set of predicted values representing the smallest possible deviance from the observed values. When the two data sets are strongly associated, the prediction error will be relatively small and the result significant.

Correlation analysis

The quantification of the association between two data sets relies on a simple idea. Intuitively, it is easy to grasp: when the scores in two data sets of paired observations (i.e., observations x_i and y_i for a single participant or item) show a similar or opposite 'spread' around their mean, there is a *positive* or *negative* correlation between the two factors, respectively. Obviously, the loose notion of 'spread' offers little help when one wants to quantify the strength of the correlation. However, there are two familiar statistical tools for translating the common word 'spread' into a measurable phenomenon: the variance and the standard deviation.

Both statistical measures are mathematical tools for quantifying the intuitive notion that the spread of scores around their mean somehow refers to the *average deviance between a score and its mean.* Intuition tells us that this average deviance should be small when all scores are closely packed together and large when they are widely spread around the mean. However, when calculating the difference between each score and its mean and averaging across all these differences, we will observe that this average deviance is always (and necessarily) zero. This simply follows from the very nature of the mean: the average distance to the scores on its left on the scale must equal the average distance to the scores on its right. The variance copes with this problem by squaring the distances, as a squared number is always positive (see v). Hence, the variance is the average squared deviance from the mean (the denominator in the formula is not *n*, the number of scores, but *n–1* – we will not discuss this issue here).

$$\text{(v)} \quad \text{variance} = \sum\nolimits^{n}_{i=1} \frac{(X_i - \text{mean X}) . (X_i - \text{mean X})}{(n-1)}$$

$$= \sum\nolimits^{n}_{i=1} \frac{(X_i - \text{mean X})^2}{(n-1)}$$

The standard deviation is the square root of this variance and, hence, expresses the average deviance in terms of the same (unsquared) scale as the one on which the scores were made. As will become clear, both the variance and the standard deviation are required to calculate the correlation between two factors.

As said, the correlation measures the similarity in the spread of the scores on two variables X and Y. Using the mathematical terminology above, one should be able to measure how, for a set of paired observations, the deviance on Y moves 'in synchrony' with the deviance on X. This idea of 'moving together' refers to the mathematical notion of *covariance,* which quantifies to what extent the deviance scores on Y co-vary with the deviance scores on X. In order to understand this, imagine two sets of observations on X and Y that are exactly equal. Then, the covariance necessarily equals the variance on X (or Y, as the sets of scores are equal). Indeed, when X_i moves relative to its mean, Y_i (which equals X_i) obviously moves the same distance. Hence, the covariance between X and Y can be expressed as:

$$\text{(vi)} \quad \text{covariance(X, Y)} = \sum\nolimits^{n}_{i=1} \frac{(X_i - \text{mean X}) . (Y_i - \text{mean Y})}{(n-1)}$$

where X and Y are equal, such that (vi) is actually identical to formula (v) for determining the variance on either X or Y.

Obviously, two sets of scores are in virtually all cases unequal, so that the covariance almost never coincides with the variance on X or Y. Nonetheless, the formula for measuring the covariance between non-identical sets of scores is also expressed by (vi). In the preceding paragraph I tried to make the rationale behind the mathematics transparent by using the same sets of scores on X and Y. As this logic can be extended to any X and Y, formula (vi) applies to any set of paired observations.

However, the correlation between two sets of scores does not equal their covariance. In order to determine the correlation, we need to know how the observed covariance between X and Y relates to their maximally possible covariance. This can be done by dividing the observed covariance by this maximal covariance. As we have seen, when two sets of scores on X and Y are exactly identical, their covariance is maximal. It equals the variance on X (or Y), which in turn equals the squared standard deviation on X (or Y). Hence, for two identical sets of scores one can calculate the correlation by dividing their actual covariance (=variance X) by their squared standard deviation, as is shown in (vii):

$$\text{(vii)} \quad \text{correlation} = \frac{\text{variance X}}{\sigma_x \sigma_x}$$

The outcome is 1, indicating that the correlation is maximal, which is obvious as the scores on X and Y coincide. When X and Y represent different sets of scores, the same logic applies: the maximal covariance that is possible between X and Y is expressed by the product of the two standard deviations: $\sigma_x\sigma_y$. Hence, the correlation between any two sets of paired observations on X and Y is expressed by (viii):

$$\text{(viii)} \quad r = \frac{\text{covariance(X, Y)}}{\sigma_X \sigma_Y}$$

where r is the symbol for the correlation coefficient.

The correlation between two variables falls within the interval [–1, 1], where –1 refers to the highest possible negative correlation and 1 refers to the highest possible positive correlation. When r is negative, positive deviances on X correspond to negative deviances on Y (and vice versa), when r is positive, positive (negative) deviances on X correspond to positive (negative) deviances on Y.

Regression analysis

Regression is a statistical technique that is closely related to the concept of correlation, in the sense that a high correlation between two variables ensures a significant regression analysis on the two variables. The purpose of the regression technique is to assess how well the y values on the dependent variable can be predicted from the x values on the independent variable, more particularly, by assuming that there is a linear relationship between the two variables. A linear relationship means that, in the ideal situation, the (x,y) couples fall on a line. Mathematically, the equation for a line is written as $y = ax + b$, where a and b are constants. For instance, the couples (5,14), (6,16), (7,18), (8,20) fall on a line with the equation $y=2x+4$. Of course, the couples in an experiment, defined by the values of the independent and the dependent variables, will never fall on a straight line. Rather than setting out from an equation, generating a set of couples, and drawing the line for the equation (as one does in a mathematical exercise), one sets out from a set of couples, i.e., the points in a coordinate system, and attempts to draw a line through these points that provides the best 'fit' to the actual data, i.e., that lies as close to these points as possible. The best fit is obtained when the line is drawn in such a way that the average difference between the actual y values and the predicted y values by the linear equation reaches a minimum. Note that the previous sentence is an intentional error to make the goal of regression analysis conceptually clear: the distance between the line drawn through the set of data points must lie as closely as possible to these points, on average. The error is that the average difference between observed and predicted y values is always zero (the sum of positive differences is exactly the opposite of the sum of negative differences), which is why the relevant measure that is used is the squared difference. This method of looking for the best fit is known as the least squares method. Hence, the task of the algorithm that determines the best fitting regression line is to choose the values of a and b in the equation y(predicted)=ax+b, so that the sum of the squared differences between actual and predicted (by the equation) y values is as small as possible. Note that these differences represent the estimation error, so that the actual equation for the observed y values equals ax+b+error. Needless to say, the smaller the total amount of error in the model the higher the likelihood that the regression analysis is significant.

To finish, note that designs with more than one independent variable can be analyzed by using the stepwise multiple regression technique. Suppose that one wants to find out whether word recognition times depend on the word's frequency and its number of morphologically related words. In such a technique one first enters one of the two variables (say word frequency) and has the model estimate the a and b parameters for the linear relationship between the recognition times and word frequency. The error for each item, i.e., the difference between the observed and predicted recognition time (the so-called residual) is unaccounted for by word frequency and is used, in a second step as the new y values for a second regression analysis (hence: stepwise) in which the other independent variable, the number of morphological relatives, is used as a predictor for the residual reading times. Again the a and b parameters of the best fitting regression line are estimated. At each step the significance value for the independent variable entered at that step is calculated. Whether or not significance is obtained depends on the size of the error.

4. Conclusion

In this chapter I have positioned the experimental method with respect to other ways of doing research: theoretically-based research and various forms of empirical research. Furthermore, I have tried to describe the essential aspects of this method: (i) the major methodological concepts that are involved when discussing an experimental design, (ii) the rationale behind statistical significance testing, and (iii) the illustration of this rationale by presenting the logic behind several frequently used statistical tests for analyzing experimental data. Thus I hope to have offered the reader a toolkit for designing and analyzing experiments.

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Language acquisition

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1. Introduction

The study of language acquisition is a multidisciplinary enterprise, in which various disciplines meet. Linguistics is a first discipline in this context: linguists describe children's language in terms of the structural characteristics of the child's language production and try to capture the commonalities shown by children acquiring different languages as well as differences in the acquisition process. They ask questions such as: how does typology influence the acquisition process? What are the individual differences between children acquiring the same language? Psycholinguists and psychologists study the social and cognitive underpinnings of language: the socio-cognitive dynamics of language acquisition (given that language is not acquired in a social vacuum), and the cognitive processes involved in language production and comprehension, such as the role of perception, memory, attention, etc. Neurolinguists try to unravel the genetic bases of language by studying brain development processes associated with the emergence of linguistic communication. The list of disciplines is not exhaustive: there are indeed audiological, biological, ethological, evolutionary, psychological, sociological and other aspects of language acquisition that are not properly captured by our initial enumeration of so-called 'hyphen-linguists'. And once we start thinking about delayed and disordered language acquisition, still other disciplines have proven their relevance, such as communications disorders, or medical informatics and robotics if we think of situations like hearing impaired children with a cochlear implantation, etc.

As a matter of course it is quite a haphazard enterprise to even try to get an overview of the main lines of the research in language acquisition, since the disciplines involved are so diverse and entwined in such complex ways. For instance, a novel discipline termed 'artificial life' has arisen since the early nineties. Researchers in that field are involved in fascinating programs like the construction of 'software agents' by 'evolutionary computation' and even 'hardware agents' or 'robots' that are meant to communicate with the outside world, travel in cyberspace (the 'world wide web') to gather information, learn language(s), and perform all kinds of tasks that are considered to be intelligent. Some of the questions faced by 'artificial life' are quite analogous with the ones formulated by researchers involved in 'real life' language acquisition, and, surprisingly, some of the answers that pop up in the artificial life literature remind the (psycho-) linguist of some of the relatively neglected areas in his/her own discipline, such as the relationship between ontogeny and phylogeny (since a society of robots creates its own language, which develops and changes), or the consolidation of language varieties (dialects, sociolects, and the like).

Notwithstanding the inherently interesting nature of the research in these various disciplines, we will concentrate in this chapter on what we consider to be some of the main issues and current controversies in language acquisition research and theorizing.

In the first days of studying child language, interest focused virtually exclusively on the earliest stages of language acquisition, the period of birth to three years (Brown 1973). There were a number of reasons for this. First, this was perceived as the period when drastic changes are observed in the child, when the 'major action' so to speak takes place, the years that witness the emergence of language in children. Indeed, it was clear from the start that language learning taps the most fundamental cognitive resources in the child and that accounting for it involves probing the crucial relationship between language and cognition, universal principles and particular languages (Johnston 1985; Peters 1985; Slobin 1985). More important, the puzzle of language learnability clearly held one of the major keys for validating current models of language, providing evidence for controversial claims about linguistic theory, and most specifically, the nature of syntactic knowledge and its origin (Bates & MacWhinney 1987; Clahsen 1992; Goodluck 1986; Pinker 1984). This still constitutes the main motivation for linguists' continuing interest in language acquisition and learning (Gopnik 2001; Pinker 1994; Plunkett & Sinha 1992; Tomasello & Brooks 1999).

From a practical point of view, there was a huge need in the 1970s and 1980s for mapping out for the first time, using systematic and objective psycholinguistic tools, the highway to language in the sense of developing phonological and lexical inventories (Clark 1993; Locke 1986), breaking the grammatical code and relating it to semantics (Bowerman 1985, 1986; Carey 1982; Maratsos 1982), and interacting with their environment (Bruner 1981; Snow 1986). Core studies in English led to a proliferation of studies charting stages in language development across the world's languages from Hebrew to Swahili and the consequent establishment of models of universal steps in linguistic acquisition (Berman 1986; Slobin 1985, 2001). Expanding crosslinguistic evidence resulted in reawakened interest and further studies in the early stages of linguistic development in quest of understanding how language typology, cognition, and culture interface in acquiring linguistic concepts and categories (Bowerman & Choi 2001).

As soon as the early-years picture stabilized, it became clear that language development makes major headway beyond the age of three. Important morphological and syntactic constructions emerge and consolidate in the preschool years, accompanied by lexical reorganization and the emergence of narrative structure — all signs of ongoing changes in children's language systems beyond the age of 3 (Berman & Slobin 1994; Bowerman 1982a,b). A small number of early studies pointed the way towards the investigation of children's language after age 5, focusing especially on high-order cognitive changes and resulting late-emerging syntactic distinctions (C. Chomsky 1969; Karmiloff-Smith 1986). The picture that emerged at the end of the 1980's in the mainstream developmental psycholinguistic literature was that the most important, interesting and relevant linguistic development takes place between birth and age 5, with some additional fine-grained morphological and syntactic acquisitions after it.

But is this the whole picture? Most researchers would agree that children growing up in a monolingual environment have access to the vast majority of morphological and syntactic structures of their language before they enter school age. Nonetheless, a five-year old hardly matches an adult or even a twelve-year-old in linguistic proficiency. Evidence has been accumulating to the effect that language acquisition is a protracted process, which is not over by age ten or twelve, and that considerable changes in all linguistic domains occur in the language of older children and adolescents (Berman & Verhoeven 2002; Nippold 1998; Ravid & Tolchinsky 2002). These in fact render the language of adults as different from that of adolescents as that of adolescents differs from the language of twelve — year-olds.

The aim of our chapter is thus to provide a comprehensive overview of linguistic development from infancy through childhood to late adolescence, embedded in various relevant theoretical and methodological contexts. We start with an overview of the main issues and controversies in the field.

2. Central issues and main controversies

Explaining child language acquisition has always been a fascinating and controversial endeavor, since this is the most important cognitive achievement in infancy and childhood, which underlies almost every other communicative, social and psychological ability. In this section we review some of the main controversies in the domain. We will start with the nativist theory of language acquisition that has reigned over the domain for several decades. We will show how the notion of nativism, as it 'emerged' from learnability theory, is currently being revised. First of all, it is not controversial anymore that some parts of humans' ability to acquire language is innate (Section 2.1). But *innate* in what sense? And what exactly is innate: linguistic knowledge, general cognitive or specific linguistic abilities? In Section 2.2 we introduce the issue of modularity (intimately tied to innateness), and we briefly sketch the state of the art of the debate about modularity, innateness, and domain specificity, taking into account the current neurobiological evidence and evidence from language acquisition pathology.

The 'cradle' of *nativism* is sited in grammatical, especially syntactic acquisition; however innate mechanisms and knowledge have also been proposed for what in the Chomskyan tradition was considered to be the only component of language that needed learning (rather than acquiring), namely the lexicon. The studies reviewed in Section 2.3 show a growing tendency of taking into account the structure of the ambient language in order to explain children's lexical acquisition and apparent crosslinguistic variation. The latter point brings us to the swing in current thinking about language acquisition from a nativistic to an empiricistic or data-driven perspective. This shift of perspective was heavily influenced by the model of *connectionism* that we discuss in Section 2.4. The empiricist approach advocates a new learning mechanism, namely bootstrapping (Section 2.5): children start from imperfect information which they gather from various sources and which they compile in order to crack the linguistic code. Finally, in Section 2.6 we will highlight one of the current main emphases of acquisition research: cross-linguistic variation, variation among different children and variation within a single child.

2.1 Nativism

Since the seminal writings of Noam Chomsky, the notion of 'nativism' has been very prominent in the study of language acquisition. The gist of the argument that Chomsky (1965) put forth was that at least some aspects of language were innate: a child is born with a Language Acquisition Device which permits her to acquire the grammar of the ambient language. In later formulations (Chomsky 1986), the child is said to have an innate idea of Universal Grammar (UG), i.e., the universal principles that determine the form of any human language, and the parameters that determine the highly restricted variation between languages.

The main arguments leading to this proposal relate to the issue of the 'learnability' of language. The central and traditional 'poverty of the stimulus' argument stipulates that there is such an enormous discrepancy between the highly abstract grammatical knowledge that the child has to acquire and the underspecified nature of the phonetic strings that the child hears, that there must be an innately guided discovery procedure. The child's search space must be restricted in some way, otherwise it is inconceivable that a child can discover the grammar of her language in such a short period of time. Moreover, the language that the child hears is 'degenerate': it is competence (that is, shared and abstract language knowledge) filtered through performance (actual language usage) and, hence, ill-formed in various ways. (See Snow (1995) for an historical overview of how Chomsky's anecdotal evidence for the poverty and degeneracy of the input was challenged by research investigating the characteristics of Child Directed Speech (CDS); see also the 'twin' volumes Ferguson & Snow (1977) and Gallaway & Richards (1994).)

This formulation of *the logical problem of acquisition* should be distinguished from the *empirical* problem: language acquisition is a staged process. The child's language shows a growing complexity, which can be seen as a succession of grammars, each incorporating more and more aspects of the adult grammar. The growing complexity of the child's language is thus conceptualized as reflecting the growing complexity of the underlying grammar(s). Hence the empirical problem is: what determines the developmental sequence in language acquisition?

There are various answers to this question. One possible explanation is to assume that acquisition requires *maturation*: not all components of Universal Grammar are available to the child from the start (Radford 1988, 1990), and it requires neurological maturation for this to happen. Another explanation stipulates that all required knowledge is present and available from the start of the learning process at birth, but interdependencies between grammatical parameters make it a protracted process: parameters are ordered and the setting of parameters follows a certain ordered path, in the sense that the fixing of one parameter is dependent upon the prior fixing of another parameter. This type of learning was proposed, for example, for prosodic development by Dresher & Kaye (1990). A third explanation is more lexically based. For instance, Clahsen (1990) proposes that the emergence of syntactic structures is dependent on the acquisition of certain lexical items. In particular, Clahsen et al. (1996: 6) claim that "[…] phrase structure positions are said to emerge gradually in children's grammars, and the creation of new positions and features in phrase structures is driven by the child's learning of words and morphemes".

Thus a concomitant topic is whether there is *continuity* between the child's grammar and the eventual end-state, the adult grammar. The *continuity hypothesis* (which has been formulated in various forms) assumes that the adult grammar is basically predefined, and that the child has to make a number of critical decisions (parameter settings); but essentially the child's linguistic knowledge is adult-like. On the other hand, it is assumed that the child's grammatical knowledge lacks essential pieces of information that have to be acquired in the long run, and this acquisition implies major restructurings (i.e., noncontinuity) of the grammar. Note that the issue of continuity is independent of the issue of innateness: no matter what point of view one takes, the question is whether the linguistic categories the child uses in her language production and comprehension are essentially the same as those used by adults. (Psycho-) linguists take this more or less for granted, be it only for the simple fact that an alternative is basically lacking and — to our knowledge — has hardly been explored.

We started this section with Chomskyan nativism, a theory that was formulated in the context of 'learnability'. However, over the years the notion 'innateness' was re-defined in quite different ways. Elman et al. (1996) provide an excellent discussion of the various definitions that have appeared, ranging from innate features or abilities common to many species (such as the ability for auditory discrimination that humans share with other species like chinchillas, Kuhl & Miller 1975), through species-specific innate features and abilities of humans in particular, to faculty-specific innate features and abilities of grammar acquisition such as those proposed by Chomsky. Locke (1999) adds to the notion of innateness an interesting thought, which in fact sets the stage for a research agenda that has only been implicit for many students of language acquisition. He notes that, ultimately, linguistic behavior is produced by our genes, maturation and experience; but, ultimately, all behaviors depend on genes, maturation and experience. Hence, to make this claim interesting at all, we have to find out how these factors interact to produce the linguistic capacity: if language is indeed a uniquely human ability, and/or if language requires faculty-specific abilities and features, a theory of language acquisition should look rather different from theories of behaviors that cut across species and/or that cut across faculties. Or, as Braine (1992) phrased it: the fact that particular ingredients of language acquisition are innate is undisputed, but exactly how do we get from genes laid down at conception to syntactic categories two and a half years later? We are a long way from being able to answer this question (Bates 1999).

2.2 Modularity

Modularity refers to the compartmentalization of knowledge in the mind. A *module* is a specialized, differentiated and encapsulated mental organ, which, according to Fodor (1983), has evolved to take care of specific knowledge that is of crucial importance for the species. Language is one of these hardwired cognitive systems that is crucial for the species and has therefore evolved into a separate module. In essence this means that language is independent from other cognitive systems, and within the linguistic modules various modules (syntax, phonology) also operate independently.

Fodor (1983) pinpoints various criteria for distinguishing hardwired, independent modules from learned behaviors: modules process information in a characteristic way (encapsulated, fast, data-driven, unconscious, blind to all other information, indifferent to other cognitive modules, etc.). However, this type of information processing is also characteristic of learned behaviors that are largely automatic when reaching behavioral mastery. But modules also have a specific biological status: modules are built-up in a characteristic sequence and break-down in a characteristic way, and they are localized in the brain. Hence the language module is a kind of 'mental organ'.

The issue of modularity is closely connected to the domain-specificity of linguistic processing. For language acquisition, this question is as follows: Is language development a function of domain-specific or domain-general processes and representations? In other words, does a child use the same processes and/or knowledge structures for acquiring language as well as for learning other cognitive skills? Or does language acquisition require a dedicated module, a 'mental organ'? This question is high on the research agenda of the community, and input from the neurolinguistic front is currently throwing important light on the issue.

Liz Bates (1994, see also Bates 1999; Bates et al. 1992) argues that in fact three issues are confounded in the debate: *innateness*, *localization*, and *domain specificity*. As to innateness, the claim is that something about language (acquisition) is innate — a claim which has to be true, since we are the only species to acquire language in its fullest sense (symbolic lexicon and syntax, Deacon 1997). As to localization: the claim is that there are specific areas in the brain that are dedicated to language processing. This claim also appears to be uncontroversial, judging from the neurolinguistic literature, though there is accumulating evidence of brain plasticity and reorganization when the default conditions do not hold. Bates (1994: 136) argues: "The real debate revolves around the mental organ claim. Are the mental structures that support language 'modular', discontinuous and dissociable from all other perceptual and cognitive systems? Does the brain of a newborn child contain neural structures that are destined to mediate language, and language alone?".

This issue has not yet been fully cleared out. On the one hand, consider the deficit commonly referred to as Specific Language Impairment (SLI), a disability that is claimed to be purely linguistic, since there are no concomitant cognitive or neurological deficits. Fletcher (1999) claims that SLI occurs because language development depends upon domain-specific processes, with the consequence that it is possible for a child to exhibit impaired language development while showing no other psychological or cognitive impairments. Thus SLI seems to point at modularity and domain-dependence.

On the other hand, Bates et al. (1992) review an impressive amount of developmental neuro(bio)logical studies that seem to contradict the notion of specific brain regions solely responsible for linguistic processing: first of all, the evidence point out that particular brain regions that mediate language acquisition in the first year of life are not necessarily the regions that mediate processing and maintenance of language in adults (p. 24). Secondly, instead of a straightforward one-to-one correspondence between neurological developments that 'cause' linguistic developments in the child, there is accumulating evidence for a complex bidirectional interaction between neural and linguistic (or more general: behavioral) developments.

2.3 Lexical principles

Innate knowledge and/or mechanisms have also been proposed for other domains than grammar or syntax. For example, consider the ongoing debate about children's construal of novel word reference. The rapidity with which young children acquire words has led to contradictory models of how a novel word is inferred. One view attributes knowledge of the conceptual difference between discrete objects and substances to language learning which informs the child on the grammatical distinction between count nouns and mass nouns (Quine 1960). On this view, individuation of objects comes from the linguistic domain of noun quantification in natural languages (Carey 1994). An opposing view holds that such knowledge exists prior to language acquisition, and that it constrains and guides children in novel word learning early on (Soja et al. 1991).

Proponents of universal built-in constraints in lexical acquisition have made specific assumptions about linguistic learning mechanisms that are supposed to help children cope with the inductive problem involved in learning novel nouns. According to this view, children have innate lexical biases such as the whole object constraint, the taxonomic bias and the shape bias (Golinkoff et al. 1994; Markman 1994; Woodward & Markman 1998). Together these constraints predict that a child encountering a new noun will assume that its label refers to the whole object rather than to its parts or to properties associated with it; that there are other whole objects sharing the same category with it; and that the shape rather than the size or texture of a count noun will determine what other nouns will be regarded as sharing the same category. An alternative account of such mechanisms is proposed by Bloom (1994), who argues that syntactic distinctions of mass vs. discrete reference of nouns correspond to aspects of abstract cognition, and that young children are able to exploit such innate syntax/semantic mappings in order to learn new words, and specifically, types of new nouns.

Recent work on the early acquisition of noun reference denies the existence of innate lexical biases to explain how children handle the almost infinite number of possible interpretations logically possible for every novel noun (Landauer & Dumais 1997; Smith 1998; Tomasello et al. 1996). These studies suggest that initial lexical learning is guided by cognitive knowledge, parental guidance, world knowledge, and by attending to language-specific properties of words provided in the input. In a series of crosslinguistic studies, Gathercole & Min (1997), Gathercole, Thomas & Evans (2000) and Gathercole et al. (1999) also propose that children's lexical biases are a symptom of their reliance on regularities they discover about their own particular language in interaction with linguistic and cognitive factors.

Considerable work has been done in relation to these claims on nouns referring to collections. Collective nouns such as *forest* or *audience* are count nouns, since, for example, they take the indefinite article in English, and they can be quantified. But they are not the prototypical kind of nouns referring to discrete whole objects, since they refer to a single entity made up of a collection of other entities (*trees*, *people*). Therefore they are predicted to be problematic in acquisition in all languages, if indeed all children learning any language are motivated by built-in biases such as the whole object constraint.

A number of studies have found that collective nouns are difficult to acquire in English-speaking children. Bloom's studies on the acquisition of collectives (Bloom 1996; Bloom & Kelemen 1995; Bloom et al. 1995) present evidence that preschoolers do not differentiate between individual object and collective reference of novel nouns even when syntactic and pragmatic cues are provided unless there is explicit visual information. More evidence on children's difficulty in providing collective reference for superordinate terms and novel nouns is supplied by Huntley-Fenner's 1995 study of three- and four-year olds. Bloom emphasizes the importance of a noun with a collective reference having "an independent causal role in some conceptual domain" in order for it to be construed as an individual (1994: 319); that is, a physical entity such as a forest, for example, or a social group such as the family that has a coherent place in the structure of reality and about which children might have a 'naïve theory'. Bloom & Kelemen (1995) propose that the absence of such pragmatic cues, together with children's lower sensitivity to syntactic cues than adults, may explain their results.

These findings, however, may be an artifact of the fact that the data on acquisition of nouns with collection references initially come from English-speaking participants. Recent cross-linguistic studies comparing aspects of the acquisition of nouns in English with Mandarin Chinese (Tardiff et al. 1999), and with Japanese (Imai & Gentner 1997) suggest that culture-specific input factors in maternal speech and language-specific factors such as count/mass syntax affect children's performance.

The studies that Gathercole and her colleagues have conducted compare children's construal of noun referents in English, Korean, Spanish, and Welsh, four languages with varying degrees of overt singular/plural and count/mass marking and with distinct properties of marking nouns in context: many individuated contexts in English and Spanish, fewer Welsh nouns in individuated contexts, contrasted with nouns with collective reference, and few individuated contexts in Korean. Children acquiring these different languages gave different response patterns consistent in various degrees with the whole object, taxonomy and shape biases. English- and Spanish-speaking children were found to favor same-shape responses and to perform more in line with the whole object approach. In contrast, Korean-speaking children favored same-substance responses, and Welsh-speaking children did not perform in accordance to the whole object approach. These studies also indicate that as soon as children understood the task at hand, they responded to new words in ways that are consistent with the adult language and that consistent and obligatory singular/plural syntax affects children's response patterns (Gathercole & Min 1997; Gathercole et al. 1999; Gathercole et al. 2000).

2.4 Empiricism

Contrary to the position that the bulk of the child's grammatical knowledge is actually pre-wired and is discovered by special procedures, there is the position that the child comes equipped with particular processing strategies to the task of language acquisition, however much of what is learned emerges through the interaction of the child's mind and her environment.

Take as an example the development of speech perception. Newborns have been shown to be able to discriminate all human speech sounds, and their perception is categorical (Eimas et al. 1971). This ability to discriminate attested universal distinctions in phonetic space seems to point at an innate and highly specialized 'speech detector' (Eimas 1985). However, it has also been shown that soon after birth children are able to discriminate their native language from a foreign language and not able to discriminate two foreign languages (Mehler et al. 1988). Moreover, newborns have been shown to prefer their mother's voice and to react to recurrent mother's speech pre-natally (De Casper & Fifer 1980; De Casper et al. 1994; Moon et al. 1993). These abilities can hardly be characterized as 'innate': even though children are born with a propensity to listen to speech, the details of the child's abilities at birth seem to indicate unambiguously that they have learned from what they heard. These findings suggest that even before birth, children are learning from the ambient language, exploring the regularities that appear in the 'noise' that they hear.

During the first few months of life, infants acquire an impressive amount of knowledge about their environment, and especially about their native language. For instance, inter- or cross-modal knowledge reaches a surprisingly high level. Kuhl & Melzoff (1984) showed that two-, to three-month-olds can detect discrepancies between a speech sound and the visual display of a face that they see. In order to test this, they placed infants in front of two visual displays, one of which showed the face of a person pronouncing an /a/ and the other a person pronouncing an /i/. In between the two displays was a loudspeaker; when one of the speech sounds was played, the infants looked significantly longer at the display with the face that matched the sound that they heard, thus suggesting that already at this young age, they were able to link the 'mouth' that produces a sound and the actual sound (a form of 'lip reading', so to speak). Again, even if children are born with a propensity to integrate cross-modal knowledge, the details of their behavior at two months of age suggest that they must have learned a lot from their experience with sounds and faces.

During the first year of life, the child's universal discrimination abilities seem to erode: distinctions that the child was able to make in the first half year seem to have disappeared. Instead, the child homes in onto the ambient language and becomes especially sensitive to relevant features of the language she hears. Quite a number of researchers point at a development of children's preferences for the ambient language at the segmental as well as the supra-segmental level: children exhibit a preference for the predominant stress pattern of the native language (Jusczyk et al. 1993). The vowels of the language act as 'a magnet' (Kuhl 1993; Kuhl et al. 1992 showed this for English and Swedish children), and children acquire knowledge about the phonotactics of their native language, as shown by their preference for typical consonant clusters (e.g., the word-initial clusters [kn] and [sχr] for Dutch, and [θr] and [skw] for English, as shown in Jusczyk et al. 1994; Jusczyk 1997). Thus, even before children utter their first meaningful words, they have acquired a store of knowledge about the sound structure of the language they are acquiring, or at least knowledge about the statistical regularities in the speech signal they are exposed to.

These and many other findings have given rise to an interest in the possibilities of a data-driven or empiricist approach to language acquisition. Two common themes recur in this context: (1) what is the nature of linguistic knowledge? As shown in the previous paragraphs, children acquire knowledge in their first year, but what is the nature of this acquisition? Is it symbolic, i.e., does an eight-month-old have access to highly abstract knowledge about the phonotactics of his native language? (2) What is the nature of the learning mechanisms? Can knowledge about language structure and use be abstracted from the input language? Can the child generalize over the input to arrive at a grammar of the language? Or, are innate mechanisms required for restricting the possible grammars that the child may construct?

Instrumental in this interest in data-driven approaches to language acquisition was the rise of *connectionism*, marked by the highly influential work of McClelland & Rumelhart (1986). It culminated in a volume written by Elman, Bates, Johnson, Karmiloff-Smith, Parisi and Plunkett in 1996 entitled *Rethinking innateness*, in which the ideas about innate linguistic knowledge and processing were questioned, critically analyzed and put into an empiricist perspective: not a simple denial of nativism, but a simple denial of a nativist learning theory without a learning subject as it figures in a Universal Grammar approach.

Connectionism has put a data-driven approach to language acquisition firmly on the research agenda: alternative models and conceptualizations of acquisition have been proposed (i.a. Broeder & Murre 2000), and the fundamental thinking about acquisition has now been rephrased in terms of 'the emergence of language' (MacWhinney 1999) in a basically cognitive-functionalist view of language (Tomasello 1998).

Why would a bottom-up approach of language acquisition be possible, given the principled denial of its feasibility in the nativist UG tradition? One important factor, highlighted by Seidenberg (1997), is the availability of large language samples (such as those available through CHILDES, see Section 3.1) and computational resources required for discovering the major statistical regularities of language and speech. Statistical pattern matching has been quite successful in areas such as speech recognition by computers. Although various recent connectionist approaches differ quite extensively in the details of their implementation, they share the view that acquisition requires the exploitation of the statistical regularities of the language that the child hears. And, analogous to the approach taken in speech recognition, the task of the learner is not the identification of a particular grammar, but the performance of a particular task.

A number of exciting findings about children's perceptual development in the first year of life and fine-grained studies of their early language production show that children are indeed able to extract the main regularities from the speech signal and that there is more than an indirect link between language input and children's early productions.

Investigations of children's speech perception in the first year of life indicate that they become attuned to the regularities in the language that they hear from very early on (Jusczyk 1997; Werker & Tees 1999; Kuhl et al. 1992). One of the most convincing findings in this respect brings grammar learning into the picture. Saffran, Aslin & Newport (1996) exposed eight-month-olds to 'words'. These words were actually strings of syllables that looked like 'bida kupa doti…', some of which presented in a random order while others were presented in a fixed order (see Aslin et al. 1998 for an elaboration on conditional probability statistics in the stimuli). The stimuli were presented while the children were playing with toys on the floor. The words were pronounced by a monotonous synthesized female voice at a rate of 270 syllables per minute. After they had heard the 'words' for two minutes, the children were tested in the following way: either the same stimuli were presented to them, or they heard exactly the same syllables but in different orders, thus breaking up the statistical structure (defined by conditional probabilities) of the original 'words'. The result was that the eight-month-olds were able to detect the regularities in the input: they discriminated reliably the 'words' that obeyed the statistical regularities in the 'words' they had heard from the 'words' they had not heard before. Hence, even after two minutes of exposure, babies are able to induce the statistical regularities in the input without reinforcement and without paying particular attention to the input. These findings were replicated: young children were shown to be able to induce 'implicitly' the finite-state grammar underlying sequences of events (such as the syllables making up words in the Saffran et al. experiment), and they were shown to be able to do that with sequences of tones (Saffran et al. 1999) and visual displays (Kirkham et al. 2002).

Thus children appear to be sensitive to the regularities that show up in the input language. These regularities also show up in their own language production. First of all, there appears to be a close overlap between the language children produce themselves and that they hear from their parents. Parisse & Le Normand (2000) studied the lexical overlap between child and adult language, and they conclude that "it is plausible that up to 90% of the combinations used by children have been heard at least once" (p. 290). More specifically, they compared 33 hours of speech produced by Philippe and the adults he is talking to (data taken from the Léveillé database in CHILDES). They show that "72% of the bi-words [i.e., two consecutive words] produced by Philippe at 2;1 (in type, and 82% in tokens) correspond exactly to adult bi-words", indeed a high overlap between the two, which may turn out even higher if a more extensive database is investigated.

This reliance on the input clashes vigorously with the view that language acquisition amounts to acquiring a collection of abstract grammatical knowledge. It leads to a number of critical questions. How can one of the generative credos, namely the creativity or generativity of the grammar, be explained in a view that stresses reliance on input patterns? Which learning mechanisms are invoked to account for language acquisition? These questions constitute the core of current acquisition research. In what follows we will briefly review some of the directions that have been taken.

Do children acquire abstract grammatical knowledge? This issue is not resolved yet: at least the view that abstract grammatical categories underlie children's language production is now seriously questioned (compare Hirsh-Pasek & Gollinkoff 1996 with Tomassello 2000). In an empiricist approach of acquisition, the possibility is explored that children start with lexically-based patterns borrowed from the input. 'Formulaic frames' (Peters 1995), 'slot-and-frame structures' (Lieven et al. 1997) are hypothesized to be children's privileged way of constructing their first complex multi-word utterances: constructions such as *See X* or *Daddy's Y* are the kind of limited scope formulae that characterize early linguistic use and that form the basis for later generalization (Braine 1963, 1976; Tomasello 2000). Under this view, abstract grammatical categories are seen to emerge only later in development.

What is currently needed in the field of language acquisition is research that starts from different analyses of particular acquisition phenomena, draw contrasting predictions from the models and empirically test these predictions. Exemplary in this respect is the study of Theakston et al. (2001) who investigate the early acquisition of verb-argument structures; it offers an analysis that relies on children's memory of input structures, contradicting Valian's (1991) model which uses abstract syntactic structures. Similarly, the study of Wijnen et al. (2001) is exemplary in that it investigates to what extent children's so-called optional infinitives can be explained in terms of input factors (as opposed to innate syntactic knowledge proposed in a UG approach). They conclude that indeed input may be a determining factor, but that also information from other sources appears to play a role, which brings us to the bootstrapping operations that we discuss below.

Creativity or *generativity* appears to be a crux for empiricist approaches to acquisition (or to language processing in general). If children rely on their memory of input patterns, how is generalization possible at all? Indeed, the standard approach emphasizes the observation that the grammar, though finite, can be used to generate an infinite set of sentences, and this capacity to generalize has provided the classical evidence that knowledge of a language involves rules (see Berko-Gleason 1958; Pinker 1999). The controversy over this issue has not yet been resolved: it has produced an enormous amount of research investigating, for instance, the use of rules in a symbolic dual-route model of morphology versus the exclusive use of associative memory in a single-route model (see e.g., Plunkett 1995 for a selective review, and a theme issue of *Cognition* on 'Rules and Similarity in Human Thinking', vol. 65 (2/3)). A crucial notion that has gained credibility in this respect is 'analogy': connectionists have brought analogical learning under the spotlight; several operationalizations have consequently been proposed and applied to language acquisition and processing (Broeder & Murre 2000).

The notion of *bootstrapping* in acquisition research has been used to describe how children use correlations between different aspects of language to infer structure. Connectionist approaches provide a generalization and formalization of this notion, which is seen to play a key role in the child's entry into language, providing the basis for identifying words, their meanings and grammatical functions, as well as the kinds of structures they participate in (Seidenberg 1997).

2.5 Learning mechanisms: Bootstrapping

Bootstrapping is a mechanism proposed to deal with the problem of how the child 'breaks' into a particular linguistic system. Assuming the child has a notion of 'objects in the world', she may use that information as an entry into the domain of parts-of-speech or lexical categories: for example, words referring to objects are of a particular kind termed 'nouns'. Thus, on the basis of already existing knowledge and processing capacities, the child uses that information in the linguistic and non-linguistic input to determine the language-particular regularities that constitute the grammar and the lexicon of her native language (Weissenborn & Höhle 2001). As the example above of 'objects in the world' and 'nouns in the language' already implies, one of the main problems with bootstrapping is that most of the time there is no completely transparent interface between the domains at hand: on the one hand, nouns do not always refer to objects alone, while on the other hand, not only objects are referred to by nouns. But: no matter how imperfect the parallelism between two knowledge domains is, bootstrapping is considered to be a useful initial aid for the language learning child.

Various bootstraps have been proposed in the literature, as we show below. Understanding how each bootstrap works derives from three interrelated queries: (1) what are the cues that can bridge two domains? (2) Is a child aware of those cues? (3) Can the child actually use those cues?

2.5.1 *Distributional bootstrapping*

Maratsos & Chalkley (1980) propose the notion of correlational learning (also referred to as 'correlational bootstrapping'), namely that children are sensitive to a set of 'distributional' properties of the language they hear, such as serial position, position relative to other words, inflections, and to certain semantic notions encoded in sentences. The child may start out by recording which words have which properties in the input. When a sufficiently large set of words are noted to have a highly overlapping set of properties, the equivalent of a grammatical category exists, and the child may then generalize. Specifically, any subsequent word observed to have one property in the intersection set is assumed to have the remaining properties automatically.

2.5.2 *Semantic bootstrapping*

Pinker (1984, and 1989 for a further elaboration) proposes 'semantic bootstrapping' as a mechanism children use for breaking into the syntactic structure of the language. The idea is quite simple: the child hears adults talk, and because she understands the scene they are talking about, she can start figuring out what the language structure is like. In other words, cognitive capacities are invoked as a bootstrap into syntactic structure. For instance: if the child witnesses a scene in which an actor is performing a particular action ('John is running', 'Mary is cleaning', 'The baby is crying',…), she may notice that the actor is the first one to be mentioned, and that the action follows. And witnessing scenes in which utterances occur such as 'John gives a book to Mary', 'The baby throws a bottle on the floor', etc., the child may notice that the thing something happens with is mentioned after the actor and the action. In so doing, the child may eventually hit upon the generalization that the relationships she understands are expressed by the order of constituents, and that the order is SVO in the language she hears. Thus, Semantic Bootstrapping claims that "the child uses the presence of *semantic* entities such as 'thing', 'causal agent', 'true in past,' and 'predicate-argument relation' to infer that the input contains tokens of the corresponding *syntactic* substantive universals such as 'noun', 'subject', 'auxiliary', 'dominates', and so on" (Pinker 1987: 407). Pinker invokes an elaborate set of innate concepts and devices in order to be able to make the bootstrapping approach work; he argues that the child is innately equipped with a large number of the components of grammar: syntactic categories like 'noun' and 'verb' are innate, and furthermore Pinker assumes that there are innately given 'linking rules' that link those syntactic categories to thematic categories such as agent, theme, etc.

The idea underlying 'semantic bootstrapping' bears some resemblance to work in the early seventies that deals with the relationship between Piagetian concepts, Fillmoreian case-like relations and the usefulness of the former in acquiring the latter (i.a. Edwards 1973). It is also quite close to the concept-first view: the child has a conceptual grasp of the world, she entertains certain concepts and these are helpful in shaping the child's linguistic knowledge.

Slobin (1986, 1991) developed the idea of prototypical scenes and their expression in terms of canonical sentence types. According to Slobin, children pay particular attention to prototypical situations in the world of reference, which constitute highly salient event types such as object transfer, physical manipulation and voluntary movements. These basic cognitive representations are encoded by various languages in a canonical way, such as SVO order in English or use of the accusative inflection in Turkish. In development children pair the event and the canonical structure, expanding the former in various ways while adhering to the grammatical form. Slobin (1981) provides evidence that markers of highly transitive scenes are acquired early on in a number of languages. For example, the ergative marker on agent nouns in Kaluli marking nouns in sentences like 'Father is cutting wood' is already present by age 26 months in Schieffelin's 1979 data. In the same way, the Russian accusative suffix marking semantic patients already occurs by age 23 months, but is restricted to sentences describing physical manipulation of objects.

The semantic bootstrapping approach is not unproblematic, though, be it only for the simple fact that the language children hear contains more than mere canonical sentence types; that the language expresses more than prototypical scenes; and that there is no straightforward relationship between concepts, meaning, and formal linguistic categories (cf. Bowerman 1989; Maratsos 1992, 1999 for critical considerations). Compare for instance English 'John *runs/is running* fast' with two equivalents in a verb-second language such as Dutch in which the main verb easily switches position ('Jan *loopt* snel'/'Jan is snel aan het *lopen*').

2.5.3 *Syntactic bootstrapping*

Syntactic bootstrapping exploits the form-to-meaning relationships in the language, as opposed to semantic bootstrapping that exploits meaning-to-form relationships. On this view, the child who understands the semantic implications of syntactic environments can recover aspects of the meanings of unknown verbs (Bloom 1994; Landau & Gleitman 1985; Gleitman 1990; Gleitman & Gillette 1995; Naigles 1990, 1996). For instance, if the novel verb *gorp* occurs in an NP-V-NP-PP sentence, it can be safely inferred that the verb encodes an action that causes an affected entity to move or change in a certain way (John *gorped*/put/dropped/… the ball into the basket). Gleitman (1990) demonstrated that adults are quite accurate at guessing what a nonce verb means when it occurs in a particular syntactic frame: if one hears 'John is gorping', the verb is not likely to mean something like 'hit' but more likely to mean something like 'scratch'. Gleitman also established that adults are fairly poor in guessing what verb was uttered when watching a scene without actually hearing what is said. In other words, learners have difficulties identifying a verb's meaning from observation of its extra-linguistic context alone.

Is this procedure useful for a language-learning child? Does the set of syntactic environments offered by mothers to the learning child inevitably place the child in the correct semantic neighborhood? Lederer et al. (1995) show that indeed the linguistic information provided by mothers is refined enough to support learning from verb frame ranges. They examined the 24 most frequently used verbs in lengthy conversations of mothers with their 12 to 25 month olds, and each verb was found to be unique in its syntactic range, and hence to provide good cues to the verbs' meanings.

The syntactic bootstrapping approach is not unproblematic either. There is still a gap to be closed: adults and children indeed appear to use structural information to figure out (part of) the meaning of a verb, and adults do seem to provide children with consistent cues. The question remains if children who do not yet know language can actually use those cues.

2.5.4 *Prosodic bootstrapping*

Prosody may be a useful bootstrap for breaking into syntax. There are indeed some prosodic cues, such as pauses, that signal major syntactic constituents, and the child may use those prosodic indicators for identifying syntactic constituents. Thus, prosodic bootstrapping suggests that acoustic cues associated with prosodic groupings in the speech stream may provide a partial bracketing of speech input into syntactically relevant units (Gleitman et al. 1988; Gleitman & Wanner 1982; Morgan 1996). Of course, prosody is not a flawless cue, not every prosodic boundary marks a major syntactic constituent: in 'The dog/chased the cat' (where the slash indicates a pause), the pause coincides with a major syntactic boundary (the one between the subject-NP and the VP), but the latter is not true in 'He chased/the big old cat' (Gerken 2001).

Young children appear to be sensitive to the prosodic structure of their mother tongue. Already in their first year of life, they differentiate utterances with a 'natural' prosody (clause structure and prosodic structure coincide) from utterances in which the prosody was manipulated for the sake of the experiment, resulting in a conflict between syntactic and prosodic boundaries (Hirsh-Pasek et al. 1987). This prelinguistic ability of the child may be a good way to crack open the high-level syntactic structure of utterances (Kemler Nelson et al. 1989).

But also other prosodic, and more general, phonological cues may assist the child in breaking into the linguistic system: there is accumulating evidence that in the prelinguistic period, roughly speaking the first year of life, children become familiar with the predominant stress pattern of the language they hear, acquire knowledge about the segmental structure of the language (such as: which segments occur? which combinations of segments occur?), and they use this type of information for tasks like word segmentation. For instance, Cutler and her colleagues (Cutler 1994; Cutler & Norris 1988) proposed that adult speakers use a Metrical Segmentation Strategy whereby they identify the onsets of new words with the occurrence of strong syllables in English utterances. These word segmentation abilities have been shown to exist in children in the first year of life, and they may facilitate the discovery of the syntactic organization of utterances: the child's developing word segmentation abilities may enable the learner, for instance, to track the distribution of grammatical morphemes within the boundaries of prosodic phrases (Jusczyk 2001).

Segmental and syllabic information may also be useful as a bootstrap. There is a growing body of evidence showing that the link between phonology and grammatical class is not entirely arbitrary. Kelly (1986) showed that there are reliable phonological cues for the assignment of nouns and verbs in English. He thought that these cues were language specific. However, Morgan and colleagues (Morgan et al. 1996; Shi et al. 1998) investigated if various 'pre-syntactic cues' such as number of syllables, presence of complex syllable nuclei, presence of coda, syllable duration, and the like are sufficient to guide assignment of words to rudimentary grammatical categories. Their investigation of English, Mandarin Chinese and Turkish shows that sets of distributional, phonetic and acoustic cues distinguishing lexical and functional items (closed- vs. open-class lexical items) are available in infant-directed speech across such typologically distinct languages. Durieux & Gillis (2001) explicitly address the question of how far the language learner can get in exploiting this type of phonological bootstrapping as a strategy in acquisition. They show that on the sole basis of segmental information and stress pattern, words can be reliable classified in one of the open class categories in 67% of the cases in English and in 71% of the cases in Dutch.

This last finding leads us to the following conclusion. What all the bootstrapping approaches have in common is that they assume a systematic relationship between properties of the input and a specific linguistic (sub-)domain. They also share the finding that the relationship is systematic, though it is not perfect (see the figures mentioned by Durieux & Gillis). This leads to the question of how these various bootstraps, that is various sources of information, are used together in order to figure out the linguistic structure of the language.

Moreover, there is a developmental question that remained untouched, namely if and how the bootstrapping strategies and their interrelations change over time. It may well be that the bootstraps are useful for initially 'cracking the linguistic code' and become less useful later on. This type of foregrounding specific types of bootstraps is to be expected, given the expanding linguistic and nonlinguistic knowledge base of the child. Moreover, changes in the bootstrapping capacities of the child may also be the result of changes in her information processing capacities, such as changes in memory and attentional resources (Weissenborn & Höhle 2001: viii), as indicated by the frequency effects for phonotactic patterns noticed in prelinguistic infants (Jusczyk et al. 1994).

2.6 Variation

Variation in language acquisition is a multifaceted phenomenon. At the level of description, variation among children acquiring the same language has received considerable attention, as well as crosslinguistic variation.

2.6.1 *Crosslinguistic variation*

To start with the latter, the monumental work of Dan Slobin (1985–1997) describes language acquisition in children from various linguistic backgrounds, focusing on the universal and the language specific patterns and on the mechanisms that can account for observed variation. The approach taken in comparing acquisition paths is intra-typological as well as cross-typological (Slobin 1997).

In an *inter*-typological approach, a group of languages is studied that shares a common set of typological features, thus making it possible to investigate variation along specified dimensions. Slobin (1997) shows that by selecting languages that belong to one typological group (an intra-typological approach), it is often possible to pull apart features that co-occur in any particular language of the type. A case in point is the acquisition of the Slavic case system. Smoczynska (1985) describes the acquisition of the case system in Polish and in Russian, which are almost identical in the two languages. It takes children acquiring Russian a very long time to differentiate all of the grammatical forms of each case suffix, with massive overgeneralization and errors. Children acquiring Polish, in contrast, use the correct form of each gender and case from the very beginning, almost without any errors. This finding is rather strange: one would expect that if the systems look alike to the linguist, the acquisition task is similar, and thus acquisition is expected to follow a similar (time-) path. The comparison of the actual input data is the key to this enigma: in Polish, unstressed vowels are not reduced, whereas they are reduced to schwa in Russian. This explains why children acquiring Polish have a more straightforward task than children acquiring Russian: the former hear clearly distinct and perceptually consistent and salient forms in the input, while the latter do not. Slobin (1997: 7–8) concludes: "What is especially important is not the fact that Russian is difficult, but that Polish is easy. We have here a clear demonstration that an inflectional paradigm based on arbitrary phonological criteria can be acquired by two-year-olds if the criteria are transparent and consistent". Thus, Slobin points out one of the determining factors of ease of acquisition, and consequently a possible source of crosslinguistic variation established by intra-typological comparisons.

In a cross-typological approach, languages from possibly very distinct typologies are compared on a specific dimension with respect to a particular phenomenon. A case in point is provided by a number of studies conducted by Gillis and Ravid (Gillis & Ravid 2001; Ravid & Gillis 2002). They compare the acquisition of spelling in Dutch (a Germanic language with sparse morphology) and Hebrew (a Semitic language with a rich morphology). The phenomenon they investigate is the spelling of homophones, and more specifically pairs like ⟨bepaal<u>d</u>⟩ ('determined') and ⟨bepaal<u>t</u>⟩ ('determines') in Dutch. Such homophonous pairs have a distinct orthography, which reflects an underlying phonological distinction, but both members are pronounced in exactly the same way. In both languages, a continuum can be devised along the dimensions 'morphological function' (e.g., root letter versus function letter) and 'recoverability' (using morpho-phonological cues to aid the learner in discovering the correct spelling of ⟨bepaald⟩ or ⟨bepaalt⟩ when these words occur in a sentence). In spelling tests administered with children in primary schools in Israel and Belgium, Gillis and Ravid found that Hebrew-speaking children were amazingly sophisticated in solving spelling problems using morphological procedures, whereas their Flemish agemates were notoriously weak in that respect almost throughout primary school. This means that children acquiring a morphologically rich language like Hebrew find it easy to use morphological cues in spelling, while children learning a morphologically poor language like Dutch find it very difficult. Consequently, learners of Hebrew seem to be able to easily transfer the morphological abilities and strategies already required in forming their first spoken words and sentences to the domain of spelling; while Dutch-speaking children, who have hardly ever had to focus on morphological puzzles, do not have a similar ability which they can transfer to written language, if needed. This finding illustrates what Slobin (1997) calls 'the operating principle strengthening' in acquisition, which can be paraphrazed as: 'whenever a solution works for one puzzle, apply the same solution in solving another puzzle'.

2.6.2 *Inter-individual variation*

Variation among children acquiring the same language was studied in detail in several studies concentrating on rather small populations (see Lieven 1997 for an overview) as well as in large sample studies (for instance the CDI study of 1,800 American children, Fenson et al. 1993). A rock-solid conclusion that can be drawn from these studies is that variation among children is vast: if one looks at onset time and the growth rates of word comprehension, word production, first word combinations, and stages of grammar acquisition, there is enormous individual variation (Bates et al. 1995). Note that we are talking about what is considered to be the 'normal' population: individual variation highlights the problem of identifying what is 'normal' and what is 'deviant', cf. the growing literature about 'early' and 'late talkers' who are at the extremes of the frequency distribution, and who should be distinguished from genuinely 'deviant' populations such as SLI children, on the one hand, and from children with clearly identifiable syndromes such as Down's, Williams' syndrome or focal brain injury, on the other.

In addition to these quantitative differences, there are also marked qualitative differences among children. Individual children vary in the sounds that they seem to babble preferentially (Vihman 1993; Vihman & Greenlee 1987; Vihman et al. 1994). In very early language development children vary in the extent to which they pick up the 'major tunes' of the language, while other children tend to produce shorter and more clearly articulated utterances, often identifiable single words (Peters 1977, 1983, 1997). The former appear to concentrate more on prosody, i.e., identifying larger chunks in the language they hear, and the latter on syllables and segments, geared towards smaller entities in the ambient language. This classification also appears in Nelson's (1973) study of early vocabulary acquisition (the first 50 words): she identifies *expressive* children who use a large proportion of 'personal-social' words and *referential* children who predominantly use 'words for objects'. These two styles actually coincide with the relative proportions of common nouns — predominantly used by referential children — and frozen phrases — predominantly used by expressive children (Lieven et al. 1992).

There is also a noticeable difference of style in children's early multiple-word speech: some children make extensive use of schwas, fillers, and reduplication to achieve meaningful prosodies, where the fillers can be seen as precursors of grammatical morphemes (Peters 1997). Others move from clear single-word utterances to juxtaposed single-words, creating the well known 'telegraphic speech'.

These and other differences that have been described in the literature (see Bates et al. 1995; Lieven 1997) raise the question of whether stylistic differences underlie each child's language acquisition, and furthermore, what causes them.

As to the first question, two learning styles have been identified, namely an *analytic* and a *holistic* style. Analytic children prefer to break up the speech stream into small units, analyze those units and then synthesize them. Holistic children, on the contrary, prefer relatively large chunks that they start using before actual analysis has taken place. This difference in approaching the task of language acquisition can be detected at all ages and in all linguistic domains (and even across cognitive domains). This finding has led to the conclusion that the two styles reflect two fairly general complementary learning mechanisms: an analytic mechanism that serves to break up units into segments, and a holistic mechanism that makes it possible for the child to remember and reproduce relatively large segments of speech before these segments have been fully analyzed and understood (Bates et al. 1992, 1995). However, research has not yet revealed a clear continuity in children's stylistic characterization: as Lieven (1997: 209) notes, there is a number of 'suggestions' in the literature such as the suggestion that "highly referential children are more likely to look telegraphic in their two-word utterances while the early learning of frozen phrases might be related to a greater tendency to produce pivot-type utterance structures in the early multiword stage". But these 'suggestions' require further scrutiny, and we are far from establishing long-distance links between learning style at the onset of language and characteristics of later language development. Moreover, establishing longitudinal stylistic differences brings along particularly difficult methodological problems (Bates et al. 1988, 1995).

As to the causes of inter-subjective variation, various proposals have been formulated: differences in the input (maternal style differences, social class differences, etc.), endogeneous factors (such as the child's temperament), explanations that focus on linguistic and cognitive factors, neurological explanations, etc.

At present we can only conclude that at least some of the relevant inter-subjective variability has been identified and charted out, but questions like the longitudinal stability of stylistic differences and their causal explanation still remain unanswered.

2.6.3 *Intra-individual variation*

Some attention has been devoted in the literature to crosslinguistic variation and variation among children learning the same language as well as to the crosslinguistic validity of those differences. The fact that a single child's speech production at a particular moment may also contain a lot of variation has been mentioned quite frequently in particular in the literature on phonological development (Ferguson 1979; Macken 1978; Menn 1976). This type of variation has not received systematic attention, though it is of special importance. For instance, in a model of acquisition that envisages the setting of parameters as the learning mechanism, the occurrence of intra-individual variation over an extended period of time is quite troublesome. In the UG tradition, parameter setting is an (almost) instantaneous process that does not allow for extended periods of oscillation. Intraindividual variation, or the lack thereof, is also crucial for acquisition models that highlight memory as a crucial factor.

3. Methodologies

How is language acquisition studied? On the whole, the literature makes two types of clear distinctions in investigating child language acquisition. One is between a *cross-sectional* method, which usually applies across a large sample of the population and compares linguistic features in groups of children of various ages (or other characteristics such as clinical or environmental characteristics), versus a *longitudinal* method, in which a (usually small) sample of subjects is investigated over a long period of time. In the first case one can acquire a large body of data from many subjects, whereas in the second one a wealth of well-situated developmental information is available from a few children or even a single child (*case study*). In both cases the researcher can draw trustworthy conclusions about the nature of language development, though the perspectives are different.

Another, albeit related, distinction is usually made between an *experimental* versus a *naturalistic* approach to language learning. In the first case, tasks are carefully constructed and populations controlled to elicit and evaluate specific target phenomena, which may not occur often enough in 'real life' to be accessible to the interested observer/researcher. However, subjects often draw on different cognitive resources (e.g., access to metalanguage) during experimental conditions, which may confound results, and there is a clear lack of supporting contextual information that may help in explaining results (Ravid 1995). Cross-sectional studies are often, though not always, experimental in nature. In the second case, naturalistic, usually spontaneous data is elicited from the child in his/her natural environment with as little interference as possible. Despite the fact that target linguistic phenomena cannot be controlled and elicited at will, this method provides us with a rich contextual background against which to evaluate the desired phenomenon (Gillis 1984; Gillis & De Schutter 1986a).

As a multidisciplinary enterprise, the study of language acquisition has 'borrowed' a broad range of methods from various disciplines, also depending on whether the researcher wants to study language *comprehension* or *production*. It is often the case that spontaneous speech studies are used to investigate children's language *production*. In that case audio/ video recordings of children's speech are made, transcribed and coded (see below). Both elicited imitation or spontaneous production can be used as a procedure: the investigator leads the child to produce a particular kind of utterance without actually modelling it. A well-known example of elicited imitation is the WUG-test (Berko-Gleason 1958). In this procedure, the child is shown a picture of a cartoon bird and is told 'This is a wug'. Then the investigator shows a picture with two or more of those creatures and says: 'Here are two/ more…'. The child is expected to give the plural of the pseudo-word 'wug'.

Various experimental techniques are also used in the study of language *comprehension*, ranging from the traditional picture-naming task (in which the child is asked to point at a picture depicting a word or a sentence); the act-out task (whereby the child is invited to act out a particular word or sentence herself, with puppets, or other toys and props); the truth-value judgment task (where the child witnesses a scenario in a cartoon or acted out with puppets, and is invited to judge the truth of a linguistic prompt), etc. Recently the 'preferential looking paradigm' has been used for studying lexical and syntactic acquisition. In its bare essence, the procedure goes as follows: the child is shown two stimuli (e.g., a horse and a cow) and hears a linguistic stimulus (e.g., 'Here is a horsie!'). The child's fixation time on one of the stimuli is measured; a clear finding is that children 'prefer' to look at the stimulus that matches the sound (Hirsh-Pasek & Golinkoff 1996; Krikhaar & Wijnen 1995).

A comprehensive sample of research methods is discussed in Menn & Rattner-Bernstein (2000); McDaniel et al. (1996). Experimental methods that are specifically suitable for testing (very) young children are reviewed in Jusczyk (1997).

In the last decades, major breakthroughs have taken place in the study of language acquisition through the emergence of new methods. We will highlight three of them, namely the establishment of large electronic corpora, the use of simulations and the use of brain imaging techniques.

3.1 Large-scale corpora collections

One of the bottlenecks in language acquisition research is the collection of large longitudinal corpora. Ultimately researchers want to investigate corpora that contain all the utterances a child produces as well as the language she hears. It would be very beneficial if corpora existed that contained all language uttered by and addressed to a child from birth till, say, five years of age. Such an effort would be applauded by the research community, but would require an incredible amount of research funding. For the sake of comparison, consider the corpus of spontaneous spoken Dutch currently being collected. The aim of the project is to collect 10 million words of adult speech. The required budget for the collection of the data, the production of basic annotations such as an orthographic transcription and part-of-speech tagging, as well as the linking of the speech signal to the orthographic transcription at an utterance level, requires approximately 5 million Euros/dollars. Roughly speaking, the corpus will contain 1000 hours of speech, which is only a small fraction of the corpus envisaged: all language addressed to and produced by a child in the first five years of life.

Nevertheless, quite a few researchers have collected and currently are collecting somewhat more sparse data of children's language, concentrating on a more restricted age range with a recording frequency which is typically around one hour of speech every two weeks. From the mid-eighties onwards, an effort has been made to trace and collect child language corpora, to transform them in an electronic format and to make them available to the research community via the internet. CHILDES, the *Child Language Data Exchange System* (MacWhinney & Snow 1985, 1990; MacWhinney 1991 and later editions) is currently the most elaborate collection of child language data. The CHILDES database contains corpora of monolingual and bilingual children between the ages of one and eight years as well as corpora from clinical populations (SLI, Down syndrome), spontaneous (unscripted) speech as well as narratives. The languages currently represented in the monolingual corpora are the following: Afrikaans, Cantonese, Catalan, Danish, Dutch, English, Estonian, French, German, Greek, Hebrew, Hungarian, Irish, Italian, Japanese, Mambila, Mandarin, Polish, Portuguese, Russian, Spanish, Swedish, Tamil, Turkish and Welsh. Bilingual span the following pairs of languages: Arabic-Dutch, Catalan-Spanish, Chinese-English, Chinese-Hungarian, Danish-Japanese, Dutch-English, English-Polish, English-Russian, English-Spanish, French-English, French-Greek, and Turkish-Dutch. In addition there are two trilingual corpora, namely English-Portuguese-Swedish and English-Hungarian-Persian.

Three crucial features make CHILDES a very important tool for language acquisition researchers. First of all, the corpora share a common representation formalism, that is, all corpora represented use a standard representation formalism, called CHAT. This means that, in principle, the general format as well as the fine details of the transcriptions and the codings are uniform across all corpora. Secondly, CHILDES also offers a set of software tools that allow users who are less skilled in computer programming to perform basic operations on the corpora they analyze. The CLAN software offers broad functionality: basic operations such as frequency counts, Boolean search, combinatorial search, etc. are at the fingertips of even naïve users. A third crucial feature is that CHILDES offers elaborate on-line documentation: all corpora are properly described, the representation formalism CHAT is defined and the ins and outs of the CLAN software is described in a detailed way.

It speaks for itself that CHILDES is a valuable tool for researchers: it broadens the empirical crosslinguistic scope of research, it permits the re-usability of expensive data, shortens the path between hypothesis formulation and testing, and provides a shared framework of analysis for the community.

3.2 Computer simulations

The availability of computer readable corpora and tools for the analysis of these corpora permits computer assisted analyses of child language data. A second methodological innovation which is just emerging as a research tool also involves the use of computers. In domains of cognitive science like Artificial Intelligence, the use of computer simulations is taken for granted. But it was not until the advent of the connectionist revolution (McClelland & Rumelhart 1986; Rumelhart & McClelland 1986) that language acquisition researchers became aware of computer simulations as tools for testing hypotheses and for proposing radically different architectures for cognition and language acquisition and processing than the ones which had held sway for many years. Nevertheless, as Bates & Elman (1993) elucidate in a very elegant paper, our thinking about language processing and the acquisition of knowledge (including language acquisition) has been heavily influenced by the serial digital computer: this is a symbolic machine which takes symbols as input and applies a series of stored algorithms (i.e., programs) to that input, to produce other symbols as output. These operations are supervised by a central processor. Bates and Elman show how connectionism turned upside down this serial computer metaphor and the implications it has/had for our thinking about language processes and language acquisition.

Another quite interesting methodological evolution that computer simulations have brought to the research community is the in-depth scrutiny of theories of language acquisition. An example comes from prosodic phonology. In the generative tradition, the acquisition of phenomena such as word stress is considered to be quite analogous to the acquisition of syntax. It requires an innate store of prosodic knowledge comprising of metrical or prosodic parameters, and each parameter needs to be tuned to the rules of the ambient language (Dresher & Kaye 1990; Dresher & Church 1992). In order to write a computer program that takes the words of a language as input and produces a correct setting of the metrical parameters, the researcher has to make fully explicit how the program goes about setting the parameters, how the program distinguishes rules and exceptions on the basis of random input data, etc. Writing such a program proved to be very complicated (Dresher & Kaye 1990). Moreover, in an empirical test of the program, Gillis et al. (1996, 2003) showed that even for a UG model with fully specified parameters, learning the stress system of particular existing languages is impossible, thus laying bare the shortcomings of the UG model. This type of empirical test of a theory shows great potential: the kinds of problems faced by a UG model that Gillis et al. (1996) and Durieux et al. (2003) discuss could never have been established unless the computational strength of powerful computers is employed.

3.3 Brain imaging techniques

In the last decades a number of techniques have been developed that allow researchers to study the brain by 'watching it work'. One technique measures event-related potentials (ERP), and it can be used to study brain-behavior relationships by measuring electrophysiological correlates of brain activity with electrodes encased in saline-soaked sponges placed on the subject's skull. ERP is characterized by a complex waveform that varies in amplitude and frequency over time and is thought to reflect ongoing brain processing (Molfese et al.

2001). Brain processing that is measured in this way can also be localized as a function of the position of the electrodes on the skull.

Positron Emission Tomography (PET) and Functional Magnetic Resonance Imaging (fMRI) are two other techniques used to localize brain activity by monitoring blood circulation. These two techniques have been used quite extensively with adults in order to describe the neural networks associated with particular linguistic processes and the identification of regions consistently activated for a particular task, such as phoneme discrimination or lexical decision (Kent 1998). A sophisticated example of such studies is provided by the examination of auditory and visual information processing. The McGurk-effect is a well-known psycholinguistic phenomenon: close your eyes and play a tape on which the syllable [da] is repeated. You will definitely hear the syllable [da]. Now repeat the tape and with your eyes open, you watch a movie (without the concomitant sound) of a person pronouncing the syllable [ba]. The amazing fact is that now you will start to 'hear' [ba] (the visual stimulus) instead of [da] (the auditory stimulus). This experiment also works in the opposite direction: first see someone pronounce [da] without sound and then hear the stimulus [da]. In a number of fMRI studies it was shown that the auditory cortex is not a singular region, nor is it restricted to information from the auditory system: visual information from lip movements can modify activity in the human auditory cortex (DiVirgilio & Clarke 1997; Rivier & Clarke 1996; Sams et al. 1991).

A huge selection of adult PET and fMRI studies is reviewed by Cabeza & Nyberg (2000). Studies with children and babies are still sparse for the simple reason that a technique like fMRI requires the subject to be able to hold still, lying down in a gigantic machine which emits a lot of noise, etc.; not exactly the right circumstances for young children to feel at ease and to cooperate.

In contrast, ERP studies with children have led to quite remarkable results by providing support for previous behavioral findings. For instance, Eimas and colleagues (Eimas et al. 1971) discovered that prelinguistic children show 'categorical perception', i.e., they readily discriminate between consonants from different classes (e.g., voiced versus voiceless stops), whereas it is very hard for them to discriminate two consonants belonging to the same phonetic category. ERP studies have indeed revealed that from at least two months of age the infant's brain appears capable of discriminating voiced and voiceless stops: the ERPs are different for the two types of stimuli. Thus the behavioral evidence provided in the Eimas et al. study is confirmed by ERP studies (see Molfese et al. 2001 for an overview). ERP studies have also revealed age-related differences between children as well as differences related to their level of language acquisition: ERPs measured with thirteen-month-olds are different for words children know and for those they do not yet know, but once children start acquiring new words at a fast rate at around 18 months (see below), there are dramatic changes in the topology of the ERP patterns of 'known' versus 'unknown' words (St. George & Mills 2001). This means that a particular step in language acquisition goes hand in hand with dramatic reorganizations in the way the brain handles language, in this case at the lexical level. St. Georges & Mills (2001) also recorded ERP responses to open and closed class words (content and function words) in children from 20 to 42 months. They discovered that initially the response to both types of words was the same, however subsequently the response gradually differentiated, establishing a clear link between the acquisition of lexical and grammatical knowledge. Furthermore, ERP studies are just beginning to be predictive: Molfese et al. (2001) review a number of longitudinal studies in which differences in children's linguistic abilities at age three or four are tracked back to differences in the ERPs to speech at birth.

4. Early language development: A quantitative description

Both researchers and practitioners (like speech clinicians) have the need to divide the process of language acquisition into different stages or phases. For instance, for the purpose of psycholinguistic experiments, one may want to investigate the linguistic behavior of relatively homogeneous groups of subjects in order to chart out the path of acquisition of a particular linguistic phenomenon, such as inflectional morphology (Dressler 1997). Or in order to characterize the language development of a child as 'normal', 'deviant' or 'delayed' it is of crucial importance to have a measure for language development which, ideally, can be correlated with the child's chronological age (Miller & Klee 1995).

A first proposal in this respect came from Nice (1925), who introduced the Average Length of Sentence (ALS) as a means for delineating stages in language acquisition. ALS is the mean number of words in the spontaneous language production of a child. This crude measure was further developed in Brown (1973) who proposed to calculate the Mean Length of Utterance (MLU) not in terms of words, but in terms of morphemes. Charting out a child's MLU results in a graph that shows a steady increase as the child's language production gets more complex, i.e., as her sentences grow longer. Brown also figured out that the stages he initially determined arbitrarily (Stage I = MLU 1.0–1.99, Stage II = MLU 2.0–2.49, etc.) were in fact characterized by distinct linguistic behaviors (Table 1, adapted from Ingram 1989: 50).

A one-dimensional index such as MLU can be calculated very easily, and it is still used rather frequently in the literature. However it is clear that this index relies heavily on language-specific rules for analyzing (morphemizing) the child's utterances (Arlman-Rupp et al. 1976; Hickey 1991), and the links that Brown disclosed between growing MLU and particular structural characteristics are also tied to the peculiarities of the language, i.c., English. In a morphologically rich language such as Hebrew or Finnish, morphological structures will turn up much earlier and will be initially more diverse than in English (Dromi & Berman 1982).

Table 1. Brown's five stages of early grammatical development

Stage	MLU range	Description
		The period of single-word utterances: The use of single words without any grammatical knowledge
I	1.0–1.99	*Semantic roles and syntactic relations*: The onset and acquisition of the basic semantic relations in language like Agent, Patient. Word order is the first syntactic device acquired.
II	2.0–2.49	*Modulation of meaning*: The child begins to acquire inflections and grammatical morphemes.
III	2.50–2.99	*Modalities of the simple sentence*: The active acquisition of the English auxiliary as it appears in yes-no questions, imperatives, and negative questions.
IV	3.0–3.99	*Embedding of one sentence within another*: Complex sentences appear with object noun phrase complements, embedded wh-questions, and relative clauses.
V	4.0 and up	*Coordination of simple sentences and propositional relations*: The active development of sentence, noun phrase, and verb phrase coordination with the use of conjunctions.

In addition to a simple structural index such as MLU, various other measures have been proposed: (1) quantitative sentence scoring measures such as the Developmental Sentence Score (DSS, Lee 1974), or the Index of Productive Syntax (IPSyn, Scarborough 1990); and (2) profile analyses, which attempt to plot out the child's developmental profile in a particular domain on the basis of spontaneous speech data (grammar, e.g., LARSP, Crystal et al. 1990; phonology, e.g., PACS Grunwell 1985) These measures are all language dependent, and hence have been adapted to particular languages.

Straightforward measures have also been proposed in the area of vocabulary (or lexical) development. The most popular is the type/token ratio (e.g., Hess et al. 1984 correlate TTR with a standardized vocabulary acquisition test). Note, however, that Richards (1987) questioned the use of TTR as a valid measure of lexical diversity and adapted it so as to accommodate methodological inconveniences (Richards & Malvern 1997).

A number of factors highlight the problematic nature of assessing children's language by their chronological age: variation within the pace of acquisition in a single child, immense variation among children of the same age, structural and semantic differences among languages. Chronological age is thus not a reliable yardstick and should be accompanied by language-internal measures that cast the child's progress in language acquisition. These measures have to take into account typological differences among languages as well as specific language-dependent criteria in order to be useable at all.

The best estimate of lexical development as related to chronological age comes from the MacArthur Communicative Development Inventories (CDI, Fenson et al. 1993), a parental questionnaire that was constructed in order to assess communicative (mostly lexical, to a lesser extent, morphosyntactic) behaviors in young children up to 30 months. CDI is a large-scale standardization project in which a vast population was investigated and which resulted in a highly detailed picture of lexical development in relation to age as well as lexical variation in the population (Bates et al. 1994; Dale & Fenson 1996; Fenson et al. 1994; Fenson et al. 2000; Arriaga et al. 1998; Thal et al. 1999). In the meantime, CDI was adapted for Basque, Catalan, Mandarin Chinese, Cantonese, Croatian, Danish, Dutch, English (American, British, New Zealand), German (in Austria and Germany), Finnish, French (European, Canadian), Galician, Greek, Hebrew, Icelandic, Italian, Japanese, Korean, Malawian, Polish, Spanish (European, Mexican, Cuban), Swedish, Welsh, as well as American Sign Language and Sign Language of the Netherlands.

5. Early language development: A qualitative description

From the point of view of description, early language development can be divided into several stages. The most obvious division is between the *prelinguistic* and the *linguistic* stage. The border between these stages can be drawn at the point where the child acquires her first meaningful word. This point cannot always be easily determined, since at the end of their first year of life, children produce word-like vocalizations in relatively consistent ways specifically bound to particular contexts, such as 'brrrr' when pushing toy cars around, 'boem!' when throwing things, or 'ham' for food (cf. Dore et al. 1976; Gillis & De Schutter 1986b; Plunkett 1993; Vihman & McCune 1994). At that point the child already comprehends quite a few words, although at first this ability to relate sound and meaning in comprehension is also tied to specific contexts, such as responding to his/her own name, or routines like 'byebye', etc.). Fenson et al. (1994) report that according to American parents' estimates, their children comprehend an average of 67 words at 10 months, 86 words at 12 months and 156 words at 14 months.

Most children pass through a well-delineated *one-word* stage. At this time, toddlers' words are phonologically simplified and often unstable, semantically holistic amalgams, which do not belong to discernible (or formal) grammatical categories (Berman 1986). At some point in the one-word stage, a 'vocabulary spurt' characteristically occurs, i.e., a rapid acceleration of the acquisition rate of words (Clark 1993; Dromi 1987, Gillis 1986; Mervis & Bertrand 1995; but also see Goldfield & Reznick 1990; Fenson et al. 1994 who found a more smooth developmental pattern in some children). Based on a parental report study, Fenson et al. (1994) found that at 12 months children have a cumulative expressive vocabulary of — on average — 10 words, 64 words at 16 months, 312 words at 24 months and 534 words at 30 months.

The stage at which the child only produces isolated words is followed by a stage in which first *word combinations* occur (a two-word stage is clearly identifiable in some children, but not in others, Pine & Lieven 1993). Typically word combinations take the form of 'telegraphic speech', i.e., utterances lacking many of the required grammatical morphemes and function words. These combinations indicate the emergence of the break into the grammatical system, and are accompanied by first morphological alternations, especially in languages with rich morphologies (Berman 1981). Cross-linguistic comparisons of these early utterances have revealed that by-and-large a common set of basic meanings is encoded: existence (appearance, disappearance), basic event relations like agent-action-object, change of state or location, reference to sortals, etc. (Bowerman 1973; Braine 1976).

A further (general) division of language acquisition into clearly delineated stages is not easy to achieve. After the child produces her first word combinations, there is a spurt in grammatical development, which is brought about by both a larger lexical inventory and the growing ability to compare the internal structure of words so as to start the acquisition of word morphology. At the same time, word order becomes gradually more guided by syntactic structure and less by pragmatic considerations, and first 'sentences' appear. Children learning typologically different languages pay more attention to those features of their language which carry the most valid and salient information load. Thus, for example, children learning Dutch, a morphologically sparse language, will pay more attention to word-order and lexical meaning, while children acquiring Hebrew, a morphologically rich language, will also focus on word-internal structures (Berman 1985). At any rate, it is usually the case that inflectional (grammatical) morphology (i.e., markers of gender, number, person, case, tense, etc.) emerges earlier on than derivational morphology (which constructs and relates lexical entries) due to its relative regularity, transparency, predictability, productivity, obligatoriness and general applicability (Bybee 1985). Once started, morphosyntactic development takes place at an amazing speed and various different syntactic constructions are acquired in such pace that children are said to have acquired the basic grammar of their mother tongue before the age of five. This includes the structure of simplex clauses and some complex constructions, agreement elements in the NP and the clause, most frequent and salient function words (articles, pronouns, prepositions and connectors, etc.), obligatory grammatical morphemes and basic derivational morphology, and the underpinnings of discourse (Berman & Slobin 1994).

6. Later language development

Recent studies indicate that language continues to develop through later childhood, adolescence and adulthood, so that adults' language is both qualitatively and quantitatively different from that of adolescents (Berman 2002; Nippold et al. 1997). During this period, most marked, literate lexical items and morpho-syntactic structures that characterize adult language emerge and consolidate, accompanied by complex constructions, which serve syntactic and textual functions in specific text types encountered in the course of formal education. The changes that occur in children's language are not isolated linguistic phenomena; rather, they interact with complex cognitive, social, affective and behavioral transformations which characterize late childhood and adolescence (Berzonsky 2000).

Moreover, the attainment of literacy — learning to read and write, and using reading and writing in order to learn — is a key linguistic milestone which makes a major contribution to the nature of later language acquisition.

Tracing the long developmental history of particular constructions across childhood and adolescence is particularly rewarding when considering what it means for language users to have actually 'acquired' a construction: when they can succeed on an experimental task? When they can understand it in a text? When they can actually it them in appropriate contexts?

To illustrate the importance of continuing to investigate language development beyond its early formative years, consider the acquisition of the construction of denominal adjectives in Hebrew, derived from nouns by attaching the adjectival suffix *-I* to the nominal stem, e.g., *beyti* 'domestic' (from *báyit* 'house'), *tinoki* 'babyish' (from *tinok* 'baby'), or *prati* 'private' (from *prat* 'individual'). Naturalistic data indicates that this is the last adjectival construction to be acquired in preschoolers (Ravid & Nir 2000). Denominal adjectives first emerge in children's spontaneous speech around age 6, usually in ill-formed constructions. For example, Assaf (5;2) described a sports car (adult N-N compound *mexonit^sport*) as *óto spórti* 'sportive car', and at age 4;9 he termed a mountainous area *ezor hari* for adult *ezor harari* (from *har* 'mountain'); Sahar (6;8) defined crying about a funny situation as *béxi cxoki* 'laughy crying' from *cxok* 'laughter'; and Itamar (7;0) called himself *yéled savlanuti* 'patiency child' for adult *yéled savlani* 'patient child' (from *savlanut* 'patience'). But can children who make such initial attempts at producing denominal adjectives be said to have *acquired* them?

As the next step, consider the production of denominal adjectives under experimental conditions. Levin et al. (2001) used a structured design to elicit N-A_{den} constructions (e.g., *halixa dubit* 'bearlike walk' from *dov* 'bear') in preschoolers (aged 5–6) and first graders (aged 6–7). Figure 1 shows that correct denominal adjective scores significantly increase from about 67% in kindergarten to over 80% in first grade. This leads to the expectation that denominal adjectives should be mastered in the next year or two, towards the middle of gradeschool. But continuing to watch out for the usage rather than the elicited production of Hebrew A_{den}s shows that this is not the case.

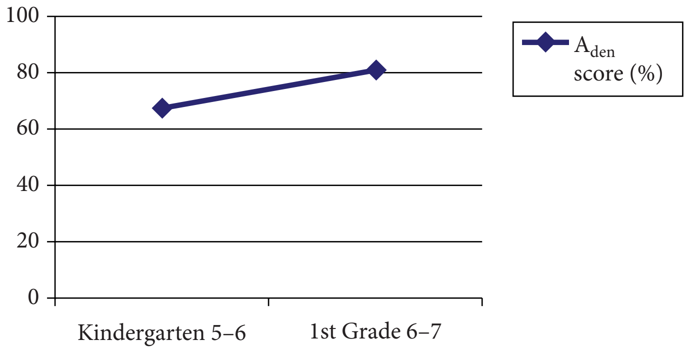

Figure 1. Increase in correct production of denominal adjectives from kindergarten to first grade (data taken from Levin et al. 2001)

Figure 2 traces the occurrence of denominal adjectives in spoken and written Hebrew texts of two genres — biographies and expositories — produced by children, adolescents and adults. These contexts foster the usage of adjectives, especially in N-A constructions (Biber 1995: 79; Shlesinger 2000). To neutralize different text length, denominal adjective occurrence was calculated over the total number of clauses in each text. Contrary to what could be expected from an over 80% success in an experimental task in first grade, denominal adjectives emerge in actual usage around age 16 in *written* texts alone, and statistically significant development continues to adulthood. This comparison teaches us not only that linguistic development indeed extends over a long period of time, but also that its nature changes in important ways over this period.

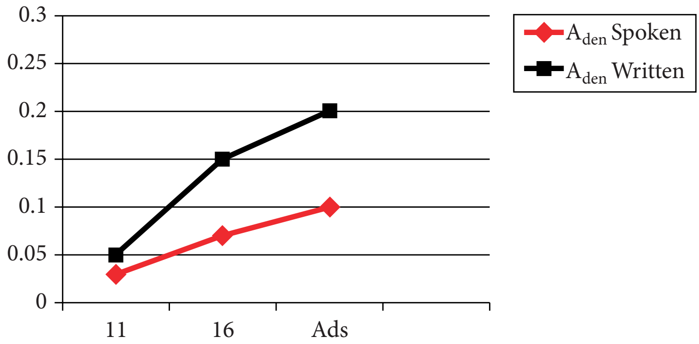

Figure 2. Occurrence of denominal adjectives per clause in spoken and written texts across adolescence (data from Ravid & Zilberbuch, in press)

Thus, in order to provide a complete and adequate account of children's development and its wider implications, we believe the research scope of language acquisition should be extended in terms of the age range, from focus on preschoolers alone to the investigation of language development until young adulthood; in terms of the domains of inquiry, from focus on the acquisition of basic morpho-syntactic categories to include later derivational morphology, the literate lexicon and complex 'written' syntax; in terms of modality, from focus on spoken language to the inclusion of written language knowledge; and in terms of the scope of inquiry, from focus on the acquisition of isolated constructions to a motivated integration of bottom-up and top-down linguistic properties of discourse. We believe that this expansion of our shared research domain may yield a better understanding of how language develops and how it interacts with the acquisition of literacy.

6.1 Development during the school years

Later language development is not an isolated phenomenon: it is firmly anchored in other major changes that occur in children and adolescents. According to our view, linguistic change is firmly anchored in four development phenomena in school-aged language users.

General cognitive development is one domain where children undergo radical changes. These involve the Piagetian shift from late 'pre-operational' to 'concrete' and then to 'abstract' operations. This means school-aged children already use semiotic systems such as language and imagery, and that they have flexible reversible reasoning which allows them to think systematically and quantitatively in terms of formalized logical structures. Adolescence ushers in the ability to deal with scenes, ideas and dimensions from a number of perspectives, to integrate different knowledge sources, to extract underlying patterns and to process hypothetical material (Meadows 1993). During later childhood and adolescence, information-processing capabilities increase significantly, leading to consequent increase in the ability to solve problems. Though scholars differ on the issue of whether it is changes in the size of the information-processing capacity or in the strategic use of this capacity, it is clear that older children and adolescents differ from younger ones in the speed, exhaustiveness and flexibility of their cognitive operations. These include the development of executive control and self-modifying production systems — the abilities to set goals, search and evaluate options, plan and monitor procedures, detect and repair problems, select strategies, eliminate inconsistencies and redundancies. The growth of information-processing capabilities derives from improvement in attentional resources and in the perception, representation, organization and integration of information (Eysenck 2001; Keil 1989). Changes in reflective thinking in adolescents enables higher-order abstract knowledge structures (metacognition) where the synthetic content of conscious knowledge becomes the target of conscious thought and subject to analysis and deliberate changes. Adolescent cognition is characterized by more complex and dense structures, on the one hand, with a higher degree of explicitation and increased accessibility to knowledge, on the other (Karmiloff-Smith 1992). Similar and concurrent changes occur in the linguistic systems available to children.

Social and affective development is another important domain which accompanies linguistic change. The Vygotskyan point of view emphasizes the central role of social interaction and guided participation as scaffolds promoting cognitive change. School-aged children experience direct and indirect interaction with more experienced partners, processes which lead to learning culturally valued skills and to reorganizing children's current knowledge structures. A Piagetian perspective points at the peer group as the main social context of development, where peers provide each other with new information, mutual feedback, evaluation and debate that contribute to better problem solving (Gauvain 2001). Erikson's model describes how development brings on a consolidated sense of ego identity, that is, a perceived sense of inner sameness and self-continuity. During schoolage children participate in learning valued skills while adolescents achieve a stable sense of personal identity and self-knowledge (Berzonsky 2000). All three models characterize the period of later language development as a time of fundamental social, affective and cognitive changes fostered by social interaction.

Schooling is a third factor in constructing the underpinnings of later linguistic development. The transactional and complex nature of human cognitive development requires the symmetrical (peer) and asymmetrical (teacher-student) interaction typical of school (Gauvain 2001). Beyond the changes brought on by the acquisition of literacy (see below), school learning is crucial in providing young language users with three important extra-linguistic sources of language-relevant knowledge. One is a systematic disciplinary foundation in world-knowledge necessary for interpreting spoken and written texts. Another is a large lexically-specific vocabulary relating to different arts and sciences extending the stock of nouns, verbs and adjectives in the advanced lexicon. A third school-based language aid is the encounter with a variety of genres (narratives, poems, expositions, instructions, informative texts, mathematical problems, historical texts, biographies, scientific treatises, etc.). This encounter familiarizes children with the language characteristics typical of various text types.

Literacy. Learning to read and write is a key intellectual achievement accomplished in the early school years (Olson 1994) which has major implications on language development. The basics of reading and writing are acquired in the early grades of primary school, while in later grades children already use literacy to appropriate school knowledge. But beyond its obvious role as the main instrument of learning, literacy is crucial in fostering the advent of later language acquisition in directing learners' attention to *written* language as their primary source of information about language.

Literacy provides access to written language in two different routes (Ravid & Tolchinsky 2002): written language as *discourse style* and writing as a *notational system*. Written language as discourse style involves the variety of genres appropriate for 'language in writing', such as legal discourse, academic writing, or newspaper reporting, each with its typical thematic content, global structures and linguistic features. Writing as a notational system, in contrast, involves an ordered set of graphic signs used for composing messages in the written modality (Harris 1995).

Learning to read and write establishes links between the internal representation of phonemes, syllables and morphemes and their written representations (Bentin 1992; Goswami 1999; Fowler & Liberman 1995; Rubin 1988). Concomitantly, written representations modify these very same internal linguistic representations (Gillis & de Schutter 1996; Levin et al. 2001). Abilities requiring more integrated knowledge such as reading comprehension are also related to analytic metalinguistic skills (Demont & Gombert 1996; Yuill 1998). Sensitivity to specific language domains, such as derivational morphology, has been shown to play a significant role in reading ability in gradeschool and highschool as well as among college students (Henry 1993; Mahony 1994; Smith 1998).

Learning to view language and use it from these two written perspectives changes the perception and use of language in adults fundamentally and permanently. While children's perception of language is mostly based on its oral form, adults' language knowledge mostly derives from their understanding and use of both spoken and written language (Nippold 1998). In this mature linguistic world, spoken language is delegated to the realm of online communication and is assigned mostly an illocutionary and affective role. Written language now constitutes a major source of linguistic items and constructs and the vehicle for metacognitive and especially metalinguistic thought processes (Karmiloff-Smith 1992; Olson 1994). Developing literacy provides learners with the ability to copy, summarize, organize, revise, edit, and integrate linguistic material as well as relate it to other texts, in interaction with a host of literate reference sources such as dictionaries, encyclopedias, guides and manuals, concordances, journals and the Internet.

Later language acquisition is thus closely related to the cognitive and social developmental trends taking place in middle childhood and adolescence, and is promoted by the qualitative and quantitative increase in school-based knowledge described above.

6.2 The nature of later linguistic acquisition

Later language development takes place on two distinct planes. On the one hand, linguistic *abilities* undergo fundamental changes towards metalinguistic control, rhetorical expressiveness and a higher order of semantic flexibility. On the other hand, the acquisition of linguistic *knowledge* continues in the lexical, morphological, syntactic and discourse domains.

6.2.1 *Developing reflective linguistic abilities*

Language knowledge in children is essentially *implicit*. In everyday interaction, this complex system is typically *used* rather than *addressed* as a separate body of knowledge (Chafe 1994). In this natural context of discourse, speakers normally focus on maintaining or changing the discourse topic and their role as speaker or addressee, rather than on the linguistic form (Lambrecht 1994). The purpose of a linguistic transaction is usually informative, and so language users focus on content to achieve their communicative goals. Therefore, while talking, as in performing any other 'natural' and authentic linguistic act where language is used rather than analyzed, linguistic knowledge is applied *holistically*, to construct (or comprehend) a totality that integrates phonology, morphology and lexicon, syntax and semantics in a given context. Language users may pay explicit attention to discourse topic, to prosodic features or to lexical choice, but not to choice of syntactic construction or morphological form. While language users may be aware of their tone and intonation, pitch and volume during conversation, they are not aware of NP structure or verb aspect in the same way. These three features of *language use* — implicit, holistic and content-directed — constitute part of the natural linguistic heritage of any language speaker, and characterize speech from early on (Ravid & Tolchinsky 2002).

With increasing experience in different linguistic contexts, language knowledge takes on a more explicit and analytic character (Gombert 1992; Karmiloff-Smith et al. 1996; Van Kleeck 1982). Young children display emergent metalinguistic awareness in natural interaction through spontaneous self-repairs, 'practice' sessions, questions and observations about language. Children's ability to perform structured linguistic tasks such as inflectional changes in non-natural, experimental contexts also implies a rudimentary metalinguistic capacity (Ravid 1995). The onset and development of phonological awareness in preschoolers is an essential precursor to literacy acquisition since it involves the ability to form mental representations of distinct abstract phonological elements such as phonemes, syllables and sub-syllables and to relate them to orthographic representations (Perfetti 1987; Goswami 1999; Goswami & Bryant 1990). During the school years, other types of metalinguistic awareness develop — lexical, morphological, syntactic, pragmatic, textual — which all involve representing, introspecting about, analyzing and discussing various linguistic dimensions as separate domains of analysis (Carlisle & Nomanbhoy 1993; Ravid & Malenky 2001; Smith 1998; Wysocki & Jenkins 1987). Evidence comes from tasks requiring controlled, analytical, explicit verbalization of linguistic processes and constructs, which are beyond the capacities of young children, and which are not fully achieved before adolescence (Nippold 1998; Smith 1998).

Language awareness increases in explicitness and concurrently involves *representational reorganization* into more coherent and more accessible forms during the school years (Karmiloff-Smith 1992). For example, Ravid (1996) and Ravid & Shlesinger (2001) show that educated, literate Hebrew-speaking adults, and they alone, are able to make full conscious use of phonological information in the form of vowel diacritics in text comprehension, and that only literate adults possess both normatively prescribed as well as currently standard forms in their mental lexicon.

The linguistic abilities which develop during middle childhood and adolescence lead to a denser, more coherent, explicit and accessible format of language (Karmiloff-Smith 1992). This permits cognitive control over the form of linguistic production and implies a detachment from content, the ability to select appropriate linguistic forms, morpho-syntactic constructions and lexical expressions, to weigh alternatives, and to access non-default, less productive, marked options. Being able to reflect on one's own usage of structures and their meanings in various contexts is necessary for the cognitive activities associated with writing. The emergence and consolidation of these reflective powers in language foster the most important characteristic of mature language, which Slobin (1977) calls *rhetorical expressiveness* and which we may term *linguistic flexibility* (Ravid & Tolchinsky 2002). This is the ability to shift through modalities and registers, to access, weigh and select alternative linguistic constructs, with the view not only to provide referential information but also to language a useful tool in expressive communication. This includes not only making more interesting and witty conversation, maintaining discourse topic, using language skillfully in persuasion and negotiation, but also the growing ability to detect and correct ambiguity, comprehend and produce texts of various genres for different purposes, and to employ jokes, similes and metaphors, idioms and proverbs in their proper contexts (Berman & Verhoeven 2002; Nippold 1998).

6.2.2 *Continuing linguistic development*

Concurrent with these crucial changes in the representation and use of language, the very linguistic systems undergo fundamental changes during later linguistic development. These are of course all dependent on the particular language being learned, but general trends can be pointed out.

The most basic system which underlies all other linguistic systems is *the lexicon*. Syntactic processes employ words, and a greater variability in lexical components is necessary for constructing more complex and diverse syntactic architecture. Moreover, richer and more informative textual structures crucially depends on enhanced lexicality (Ravid & Zilberbuch in press; Ravid et al. 2002). A comprehensive report in Anglin (1993) indicates that during the school years English-speaking children's vocabularies increase at a rate of several words per day, amounting to thousands of words per year. The overwhelming majority of words in the literate vocabulary come from written language, and many of these words are learned in the context of advanced school learning and with the diversification of knowledge disciplines.

Not only does the later lexicon expand exponentially, it also changes in critical ways. Later-acquired words tend to become longer in syllables and letters (Strömqvist et al. 2002). Compare, for example, *if* with *unless*, *but* with *however* and *nevertheless*, or *much* with *considerable*. Words also become more complex, so that much of the lexicon in the school years are derived multimorphemic and multilexemic words rather than root words, e.g., *seabound*, *stipulation*, *hypercritical*, *readmission*, *bashfulness*, *salinification*, *whole wheat*, *northeast coast indian* (Anglin 1993). Even in a highly synthetic language such as Hebrew, which encodes ideas in word-internal form and does not represent all vowels in its script, longer words such as *adraba* 'on the contrary', *hitmaktse'ut* 'becoming professional', *yam ha-mélax* 'Dead Sea (literally: sea of salt)' and *beyt gidul* 'habitat (literally: house of raising)' mostly occur in written texts produced by older children and adolescents. This of course implies increased access to a wide range of morphological devices in the language, as discussed below. Much of the lexical inventory in later language development consists of larger chunks of linguistic material (collocations, prefabricated units) which are rote-learned, on the one hand, but are composed of much more than what is traditionally is viewed as a single 'word', e.g., *raise hopes, trigonometric function, staff sergeant major, give X some slack, Olympic gods, instrument landing, NATO, UNICEF*. These complex 'words' are in their overwhelming majority school-based, literate items relating to diverse disciplines, requiring broad and current world knowledge, encoding complex sub-categorized meanings such as *telephone operator*.

Two central features of the 'learned' or later lexicon are register and abstractness. Many of the new words learned from written language are rarer and marked by higher register (Andersen 1990; Biber 1995), and many of them are abstract in various ways. As a result some changes in the later-language lexicon do not have quantitative outcomes in the actual number of words since they involve expanding concrete to more abstract and metaphorical meanings, such as extending the meaning of *hot* from reference to concrete to topics, people's tempers, etc. Many complex multi-word lexemes have metaphorical meanings, e.g., *homemaker* (Anglin 1993). In fact, each of the lexical categories in the later-language lexicon undergoes specific changes. The nominal lexicon acquires more abstract nouns and derived nominals such as *knowledge*, *intensification* and *hostility* (Ravid & Avidor 1998). Verbs become more lexically specific (e.g., *trot*, *canter*, *gallop* to describe horses' movement) and the verbal lexicon acquires items which refer to linguistic and cognitive processes such as *predict*, *infer*, *imply* and *hypothesize* (Olson & Astington 1986.). Later-acquired adjectives refer to abstract and internal features of the noun described (Ravid & Nir 2000).

The acquisition of morphology and syntax does not end in the preschool years, though the major breakthroughs are indeed achieved in early childhood. In English, a language with sparse morphology, much of the early lexicon is of Germanic origin and consists of short and simple words; while many of the complexities of the derivational system are learned while acquiring longer and more morphologically complex words of Romance origin in primary school and especially in highschool (Anglin 1993; Smith 1998). In Hebrew, a synthetic language with rich and complex morphology, later-emerging morphology includes, for example, optional bound suffixation of genitive nouns (e.g., *armona* 'palace-her' — cf. analytic *ha-armon shela* 'the-palace hers') and of accusative verbs (e.g., *re'itiv* 'I-saw'him', cf. analytic *ra'iti oto* 'I-saw him'). These bound morphological options of Classical Hebrew origins are available to older speaker/writers, but do not emerge in children before school-age since they are pre-empted in early acquisition by their analytic and transparent syntactic counterparts, which are much more frequent in everyday discourse (Berman 1997; Levin et al. 2001). Though less work has been done on school-age morphology, we should expect that later-emerging systems in any language would be less transparent, salient and frequent than ones characterizing early language acquisition, and that they should be typical of more literate and specific discourse types less likely to be encountered by children.

The changes in syntactic knowledge in later language development were noticed as far back as at the beginning of the study of language acquisition. C. Chomsky (1969) noted that children under 8 were not able to process opaque constructions such as 'the doll is hard to see' and those containing verbs such as *promise* as in 'Dan promised Mary to drink the medicine'. Beyond the comprehension of such constructions, syntactic acquisitions in later language development mostly belong to two types. Some involve the consolidation of syntactic constructions which constitute alternative rhetorical options serving specific discourse functions such as passive voice and conditionals (Reilly et al. 2002). But much of the syntactic development in the school years results in longer, more complex and diverse constructions which appear in extended discourse (Ravid et al. 2002).

Finally, the most 'visible' change in later language development is the acquisition of discourse. Beyond the ability to produce narratives (Berman & Slobin 1994), children and adolescents learn to comprehend and eventually to produce a variety of textual types constrained by different communicative purposes, such as commercials, contracts, drama, field notes, instruction manuals, Internet chats, jokes, legislative documents, lists, literary reviews, manuals, medical case reports, myths, personal letters, personal narrative, petitions, prayers, recipes, resumés, riddles, scientific writing, textbooks — to name only a few (Paltridge 1997). The ability to access and employ lexical items and morpho-syntactic constructions appropriate for each genre is the ultimate test of later language development.

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Metalinguistic awareness

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1. Introduction

Theories of metalanguage have a long and venerable history in a number of traditions, from logic through cognitive science. However in recent years, an exciting new approach to the study of metalanguage — focused upon the issue of metalinguistic awareness — has emerged from empirical research on language pragmatics and metapragmatics.[1] This work moves beyond an older conceptualization of metalanguage as language that *talks about* language, analyzing in depth how metalanguage also *creates, structures, and forms* language and ongoing speech. Speakers have varying degrees of awareness of metalanguage as it both refers to and performatively formulates communication. At times, participants explicitly recognize a metalinguistic level that structures their conversation. At other times the structuring role of metalanguage may be partially or completely concealed, operating in subtle ways of which speakers are partially or totally unaware. Even in these instances, speakers' partial awareness — or even total misunderstanding — of metalanguage can help to shape linguistic interaction. Understandings and misunderstandings of the role of metalanguage may also be regularized in the form of socially-shared 'linguistic ideologies'. In this paper we outline the implications of the new, empirically-informed approach to metalinguistic awareness, locating this scholarship in relation to work on metalanguage from a number of other traditions.

We begin with an examination of different conceptualizations of 'metalanguage' and its role, tracing antecedent formulations in philosophy and linguistics (Section 1), and then presenting recent work from linguistic anthropology and sociolinguistics — with particular attention to the writings of Michael Silverstein and John Gumperz (Section 2). In Section 3, we provide a similar exegesis of varying approaches to the relationship between metalanguage and metalinguistic awareness. The next two parts of the paper (Sections 4 & 5) discuss the relevance of these concepts to analytical and empirical studies of metalinguistic

1. This focus was to a certain extent anticipated in the work of Bateson (1972); however, more recent research has moved the field beyond his broad observations regarding the phenomenon of metacommunication to more precise delineation of the mechanisms and processes through which metalanguage operates.

activity and awareness, as well as to pioneering syntheses of the language ideology field by linguistic anthropologists such as Kathryn Woolard and Bambi Schieffelin, and others. In Section 6, we briefly examine some of the research arising from cognitive, psycholinguistic, and developmental approaches to metalinguistic activity — focusing, for example, on issues such as language acquisition and attainment of advanced linguistic skills such as writing. Finally, Section 7 considers the implications of attention to metalinguistic awareness for future research.

2. Conceptualizing metalanguage

2.1 Metalanguage and object language

Metalinguistic (used as an adjective in English and a noun in French, *métalinguistique*) has come to mean different things to different traditions, even within the customary divisions of disciplines of language studies — as has metalinguistic awareness (and lack thereof). In its original sense metalinguistic awareness is linked to the concept of *metalanguage*, originally invoked in different contexts by the logician Alfred Tarski and the linguist and literary scholar Roman Jakobson. Metalanguage is contrasted to 'object-language'. The latter is used to talk of 'things' and characterizes most of natural language, while the former is used to talk of language and characterizes (according to Tarski) logic — and obviously much of linguistic discourse. This allowed Tarski (1956) and later Kripke (1975) to deal with some hitherto unsolvable problems, such as the so-called 'liar's paradox' ('This sentence is false'), by removing the truth predicate from object-language to metalanguage (see also Quine's work taking a similar direction (1960)).

Drawing upon communications theory (e.g., Shannon & Weaver 1949) to deepen Tarski's conceptualization, Jakobson (1960) pointed out that metalinguistic talk is typically embedded in communication. Thus speakers can deploy object-language — in Jakobson's terms the 'code' of the communicative interaction — but also operate at a metalinguistic level to talk *about* the code. Indeed, as Jakobson (1957 [1971]) points out in his famous article on 'Shifters, verbal categories, and the Russian verb', speakers ubiquitously rely upon duplex signs in which both functions occur simultaneously (see Verschueren 2000 for a discussion of important distinctions among Jakobson's duplex sign categories). This is characteristically done with no special awareness (as with Molière's Monsieur Jourdain, who spoke prose without knowing it). Jakobson's communicative model assumes that sender and receiver use a homogeneous code. Linguistic interaction carries with it metalinguistic information about the code; this information is a necessary aspect of communication, externalized through speech. While broader than Tarski's approach, this view of metalinguistic discourse is still restricted to talk about a presupposed object, which just happens to be language (as 'code'). Indeed, as Verschueren (2000: 440) notes, had this been all there is to metalinguistic speech — that it is language about language — it might not have merited so much distinctive treatment and attention. But just as practical reason is not theoretical reasoning about practical matters (*vide* Aristototle) — so metalinguistic speech is not in the least confined to talk about language.

2.2 Constitutive and creative functions of metalanguage

From the perspective of recent empirically-based research on metalanguage, a core function of metalanguage is its role in constituting and framing ongoing discourse. In other words, metalinguistic features can be *performatives* whose domain is discourse. They do not merely discuss the communicative code but actually shape it, because they are embedded in discourse and are morphologically indistinct from 'object-language' strings or segments (over which the metalinguistic features have functional scope). This is not universally accepted; authors who would refrain from typifying object-language as a 'vehicle of thought' may still characterize metalanguage this way, being more aware of the former's performative aspects but less so of the latter's. The bulk of this essay will explore the constitutive functions of metalanguage and the role that awareness of metalinguistic talk plays in them.

Both followers and critics of Jakobson came to doubt the notion that metalinguistic functions merely externalize code-knowledge in socially recognizable modes (e.g., Kerbrat-Orecchioni 1980). To begin with, to presume homogeneity and presupposed metalinguistic consensus regarding the code seems an over-simplistic way to conceptualize communication. In the fields of sociolinguistics and linguistic anthropology, the question of power emerged as a key metalinguistic concept: which speakers and institutions are able to frame, form, and dictate the 'code' — the vocabulary, grammar, poetical and other aspects of the linguistic interaction that are presumed to be to some extent independent of the speech event? What social structural and ideological traits — both tacit and manifest — shape discourse, and how?

The work of linguistic anthropologist Michael Silverstein took yet a further step in developing a socially-grounded understanding of metalanguage. Shaking up many traditional assumptions about the primacy of syntax and semantics, he used cross-linguistic and cross-cultural data to demonstrate the crucial structuring role of pragmatics — both in the conveying of linguistic meaning generally, and in the particular workings of metalanguage (see Silverstein 1976a, 1976b, 1979,1981a, 1981b, 1985a, 1985b, 1985c, 1987, 1993, 1996; for exegetical discussions see also Lucy 1993b; Mertz 1985; Mertz & Weissbourd 1985). Further, he demonstrated the centrality of metalanguage to how language operates in general.

Focusing on the functions of metalanguage in practice, Silverstein began by distinguishing between metasemantics (language referring to its own semantic meanings — e.g., 'A cow is a kind of animal'), and metapragmatics (language referring to its own pragmatic meanings or use — e.g., 'I didn't mean to insult you'). While many linguists and philosophers might view pragmatics as the 'frosting' on language's fundamental syntactic-and-semantic structure, Silverstein makes the case for understanding semantics as a subset of pragmatics — and, similarly, metasemantics as a subset of metapragmatics. Under this approach, language is understood as fundamentally structured around its ability to be deployed in use, in particular situations; all speech depends upon this pragmatic functioning of language. As Lucy has explained: "Pragmatics encompasses semantics as a special case when the latter is conceptualized as regularities of meaning presupposed by and instantiated in [grammaticized] patterns of language use." (Lucy 1993b: 17). Similarly, as Lucy notes, for Silverstein: "Metalinguistic activity, in this view, is fundamentally *metapragmatic*, that is, most reflexive activity deals with the appropriate *use* of language. That part of metalanguage dealing with semantics is […] a special, yet privileged subcase of the more general reflexive activity." (ibid.; see also Silverstein 1993: 43). Although the importance of pragmatics had long been recognized by many scholars, Silverstein's work highlighted the way pragmatics and metapragmatics were deeply involved in the core grammatical structuring of language — at the same time as they also provided the framework that made ongoing communication possible in practice.[2] In this sense, Silverstein built upon insights from Prague School linguists and other scholars such as Kurylowicz (1972), who analyzed deictic elements as 'founding' much of the rest of the system of language, including semantic categories.

John Gumperz reached somewhat similar conclusions in his research on 'contextualization cues and conventions', and on 'conversational inference':

> If interpretation presupposes conversational cooperation and if such cooperation must be achieved through tacit understandings conveyed in talk, then theories of interpretation cannot rest on distinctions between literal and nonliteral meanings or direct and indirect speech acts. Knowledge of the world and socio-cultural presuppositions must not be

2. Silverstein (1993: 36) notes that in order for any discursive interaction to have coherence, there must be at least one (necessarily metapragmatic) model of what is going on at the pragmatic level — a model that attributes some kind of cohesive structure to the interaction ('this is an argument; the deployment of indexicals in this exchange is ordered by an effort to be insulting'). Note that this model depends on a conception of 'interactional text' — i.e., some formal or conceptual ordering of otherwise random speech into a coherent 'text' for interaction, instantiated in the actual discursive interaction. There can be multiple models of interactional text in play in any single discursive interaction, and this affects both speaker awareness and the unfolding of the actual exchange (and with it, power and other dynamics of relationship). Thus, speaker A may read an exchange as the enactment of the interactional text 'argument' — with accompanying interpretation of certain indexicals as 'insults', while another speaker may understand the exchange as 'just kidding around' — with the very same indexicals interpreted as 'teasing'.

> regarded as merely adding additional subtleties to or clarifying what we learn from the propositional meaning of utterances. (1982: 207)

Gumperz notes that in order to communicate at all, speakers must make inferences about the overall structure of conversation (assessing, for example, whether a particular linguistic exchange is an idle exchange of greetings, or an argument, or an important exchange of information) (1982: 1–2). Silverstein would refer to this level of structuring as metapragmatic, as it involves ongoing meta-level calculations regarding the pragmatics of the speech exchange. Like Silverstein, Gumperz connects this overarching level of metapragmatic structuring, or conversational inference, with the subtle, minute-to-minute pragmatic signals that permit speakers to make assessments and convey their intentions. Gumperz characterizes these signals as 'contextualization cues', those "constellations of surface features of message form" which allow speakers to discern the overall structure, semantic meaning, and connections among parts of utterances (1982: 131). These cues are governed by shared social conventions, which permit speakers to decipher the intended meaning of cues.

These developments in anthropological linguistics and sociolinguistics opened up exciting vistas for researchers interested in the relationship between power and metalanguage. Now it would be possible to examine overarching connections between the metalinguistic organization of discourse and larger social-institutional power dynamics. This would permit us to capture the ideological structuring of society in and through language and discourse. Work in this tradition moved on to explore language in complex, institutional settings as well as in the micro-level dynamics of individual interactions.

3. Metalanguage, metalinguistic activity, and metalinguistic awareness

3.1 The problem of metalinguistic awareness

The concept of metalanguage and of metalanguage activity, even in the referential and 'aboutness' sense offered by Jakobson (1960, see above), does not necessarily entail a sense of metalinguistic *awareness*. Benveniste (1974) addresses the issue of awareness when discussing a speaker's ability to distance herself from the language — to recognize language as a communicative device distinct from herself as a subject. Further work emphasized speakers' reliance on language's reflexivity to discuss, form, and manipulate communication in various social contexts (see generally articles in Lucy 1993a). Certainly, such phenomena and processes as bi- or multi-lingualism, translation, learning to write, and manipulating language in complex, heterogeneous social contexts, involve a certain 'distancing' from language, in Benveniste's terms; it requires users of language to become more self-conscious. Once the same object-referent is both 'apple' and 'pomme', the speaker realizes that the words are not attributes of the object apple but of the English and French languages, respectively. A certain basic awareness of language's semiotic nature — the fact that it organizes not the signified ('things') but signifiers ('words') — becomes necessary for adequate, competent, or even effective use of language in these contexts.

The case is even more so in non-referential speech, such as in instances where the functions of the speaker's language are mainly rhetorical. Reflection on rhetoric by Protagoras, Gorgias, and their sophist followers, ushered in an awareness of language — its possibilities, freedom, and choices. This focused attention on the ways in which grammar is manipulable in social settings, where — to use Austin's terminology (1962) — the function that counts is perlocutionary, or affective, rather than representational ('locutionary') speech. Once a speaker confronts numerous possibilities in framing and executing her speech, language becomes less a rigorous system of representation (as in Wittgenstein 1922) and more a framework for communication that involves complex use of framing, footing, as well as poetic, esthetic, and other attributes of speech (see Jakobson 1957 [1971], 1960; Goffman 1974, 1979; Bateson 1972). These elements in turn frame, rely upon, and manipulate the communicative context of any linguistic interaction, including aspects of the relationships and power dynamics among speakers (see *infra*; see also Duranti 1997; Verschueren 1995, 2000). Metalinguistics thus becomes a potentially liberating force with respect to the powerful tendency of speakers (particularly Western philosophers and linguists) to concentrate unduly upon reference, and language's referential functions in constructing meaning.

3.2 Language structure and metapragmatic awareness

This tendency to emphasize reference was a primary focus of Silverstein's seminal analyses of metalinguistic awareness (see, e.g., 1979, 1981a, 1985a). Building from the important insights of Whorf (1956) and Sapir (1949), Silverstein connects systematic aspects of language structure with speakers' access to metalinguistic awareness (on Whorf, see Lucy 1992a, 1992b; on Silverstein's analysis, see Mertz & Weissbourd 1985; Mertz 1993). Like Sapir and Whorf, Silverstein (1981a) found evidence that speakers are generally more aware of 'surface' segmentable (lexicalized) features of language — as, for example, when they are easily able to identify obviously segmented lexical 'chunks' of language ('words'), but cannot necessarily delineate more subtle grammatical categories.

Silverstein distinguishes between presupposing and creative language forms (1976b; he has also used the terms presupposing/entailing). Presupposing forms depend upon aspects of context that exist relatively independently of the speech itself, whereas creative forms act upon and change ('entail') aspects of context. For example, if I say 'that cow and this cow', I do not change the animals to which I am pointing. Furthermore, I rely upon presupposable aspects of the context to successfully convey meaning (e.g., there are cows to which I am referring, one of them is further away from the vicinity of the utterer than the other, etc.). On the other hand, if I suddenly use formal address in speaking with a close friend ('Good-bye, Mr. Bascom.'), this usage may actually alter a crucial aspect of the linguistic context, creating a new linguistic/social/pragmatic reality. Note that both presupposing and creative uses of language are heavily pragmatic and that both index context, but presupposing language is more readily specifiable in the abstract. Silverstein finds that speakers tend to be more conscious of presupposing than of creative indexicality.[3]

Silverstein (1979, 1981a) also concludes that the referential function of language is more available to conscious reflection than are pragmatic or indexical functions. Thus, it is generally obvious to speakers that they convey referential meaning by speaking (surface segmentable) words, and they generally conceive of that meaning as specifiable in presupposed terms. It is far less common for speakers to have a conscious and systematic picture of how prosody, gesture, and creative indexicals work together to shape social relationships in and through speech. And just as did Whorf, Silverstein points out that these limitations on ordinary awareness, built into language structure, affect professional scholars as well as laypeople. For example, he criticizes ordinary language philosophers for concentrating on explicit primary performatives as a model for understanding speech acts, because these performatives tend to be (1) segmented surface forms ('I promise'); (2) analyzed in terms of presupposable aspects of context ("felicity conditions", Austin 1962); and (3) located precisely at the point where reference appears to be transparently identified with pragmatic function (it 'names' what it 'does'). Yovel (2000) has extended this critique to the area of legal scholarship, where particularly in the area of contract theory obligatory relations between parties are formed in complex relational modes that cannot always be captured by presupposing models of linguistic action (such as those centering on 'offer' and 'acceptance' as the pivotal contractual 'acts').

As Lucy (1993b) notes, the Whorf-Silverstein challenge to standard linguistic and philosophical methodologies parallels similar challenges across the human sciences, which are increasingly wrestling with the problems posed by researchers' own limitations regarding awareness. In particular, when researchers have not adequately analyzed their own metapragmatic assumptions, they may miss crucial aspects of the linguistic situations they study. Briggs (1986), for example, has explicitly delineated metapragmatic problems in the cross-cultural use of social science interview formats, while Mertz (1993) has explored the ways in which researchers' own metapragmatic frameworks and assumptions might make it difficult for them to understand their informants' somewhat different frames.

3. Silverstein also distinguishes between two kinds of pragmatic function, one of which is more unavailable to speakers' conscious reflection. This second kind of function (what Silverstein dubs 'pragmatic function_2'), is defined as the way in which language functions pragmatically inasmuch as by characteristic distribution of particular forms in certain contexts of use, these forms (or rather, tokens of them), serve as specifically linguistic indicators (or indexes) differentially pointing to (indexing) configurations of contextual features (Silverstein 1979: 206).

3.3 Metapragmatic performance, social power, and cultural context

If a thorough understanding of metapragmatics opens the door for liberation from the powerful tendency of reference to dominate our understanding of language, then one of the obvious consequences of this liberation has been heightened awareness of the impact of social power on language structure and use.

Thus Kerbrat-Orecchioni (1980) notes that language's alleged homogeneity has come under powerful critique from work in sociolinguistics, linguistic anthropology, and other branches of language studies. As Camps & Milian explain,

> the metalinguistic function, even though it keeps referring to the code, diversifies its object as a consequence of the confrontation between the general reference model and the sociocultural diversity in linguistic usage. At the same time other factors which are not strictly related to linguistics but which influence the perspective on metalinguistic function need to be noted — factors related to the sociocultural background of the interlocutors as well as the setting of the communicative situation. (Camps & Milian 2000: 5)

As a result the study of metalinguistic awareness has shifted from Benveniste's focus on the intimate relation between a speaker and the language she uses (and subsequent instances of alienation from this language), to more complex communicative settings.

Two related points that emerge from a Silversteinian perspective on metalanguage are: (1) while object-language has both referential usage and performative functions in relation to the world, so does metalinguistic speech (it has a referential relation to talk and a performative function in shaping talk), and (2) even when functioning at the referential level, metalinguistic talk is itself performative in relation to language and to the communicative event. How to talk of things? What is the correct verbal approach to, e.g., description or representation? The fascinating insight here is that language's basic structure is fundamentally multifunctional: talk that purports to be referential simultaneously performs metalinguistically. And, as metalinguistic talk is always a matter of linguistic exchange and communication, power is involved as much in shaping the linguistic aspects of the exchange as in formulating its non-linguistic aspects.[4] Performative metalinguistic talk is not morphologically distinguished from referential talk. Ecclesiastics' maxim does not

4. Silverstein contrasts this more subtle, systemic form of pragmatic functioning with the more apparently purposive forms of pragmatic function — of which speakers tend to be more cognizant. His argument is that native speakers — including linguists and philosophers — often fall prey to using the more easily recognized form of pragmatic function when attempting to analyze the second, more subtle form. This results in a recurring misunderstanding of the systematic creativity of pragmatic function as a central feature of linguistic organization. Silverstein specifies this power as the ability "to entextualize under a particular metapragmatic model" (personal communication), i.e., to assert a particular metalinguistic frame as authoritative in deciphering this exchange.

hold here: there is no 'time' (or medium or locus) for seemingly-separate things to be performed separately, inter alia because, in the complexity of communication, things are never that separate. Referential and performative talk are distinguishable functionally, but not morphologically. In this language is like other aspects of life where, in the words of the late poet Yehuda Amichai (1983: 50): "a man needs to laugh and cry with the same eyes,/to cast stones with the same hands that gather/… to hate and forgive and forget and remember,/to organize and mess up and eat and digest, at once".

Like rhetorical speech, referential speech perforce involves metalinguistic manipulations inasmuch as it involves semantic and pragmatic choices. As opposed to the atomistic model of reference-referent, speech about more complex situations must, consciously or not, respond to such questions as: what is significant about a given situation? what should be emphasized? whose perspective should be expressed through this speech activity? Language cannot, nor does it aspire to give 'full descriptions' in Leibnitz's sense; its full descriptions always apply tacit, yet communicatively significant, criteria of *relevance* (Grice 1975; Yovel 2001b). Different verbal and textual approaches, arguing for different relevant elements, compete in discourse, some subscribing to what Bakhtin (1981, 1987) termed 'the general language' — which is the verbal approach accepted as stipulatively correct for any community of speakers. Metalinguistic activity thus frames not only rhetorical and performative speech but also referential speech that purports to belong strictly to object-language.

There is, as well, a further dimension — one characterizable as 'post-Foucauldian' — which has been better understood due to work by scholars such as J.L. Austin (1962) on linguistic performativity, and Silverstein and Kerbrat-Orecchioni on metalinguistics: language can no longer be analyzed only as a collective, egalitarian enterprise, where senders and receivers are constantly concerned with tuning and adjusting their mutual communicative interest for the shaping of better understanding within a discursive community. As language does things in the social world — whether in reliance on presupposed conventional 'procedures', as in Austin (1962), or, more complexly, through the ongoing, event-bound metapragmatic shaping of language itself — it becomes inherently involved in questions of power relations.[5] While, as Habermas (1984) points out, communication requires a necessary level of consensus and cooperation at the speech-act level, language is

5. The role of grammar and other linguistic structures in forming talk remains a complex and interesting issue. As Whorf pointed out, grammar can shape speakers' linguistic choices. For example, in French 'it makes hot' ('il fait chaud'); in English and French 'it rains', and the subject is the world that acts to make weather. But in Hebrew, the rain is the subject that 'descends'. While the forms of linguistic channeling available to speakers (both pragmatic and metalinguistic conventions and structures, etc.) define the scope of possible linguistic performances, speakers in concrete speech events maneuver within the boundaries set by grammar. In this individual speakers exert power over discourse, in both institutionalized and non-institutionalized contexts.

also used to *do* things in an often unequal, competitive, and even violent world. An arguably efficient vehicle for achieving this is ideological language — e.g., language that internalizes relations, power, and biases, while masking them as neutral or commonsensical (see Silverstein 1979, 1985a; Eagleton 1991). Thus language becomes a key agent of hegemony (Gramsci 1971), not merely in its representational functions but in how it shapes the way we say things (or, in Silversteinian terms, how we entextualize representations) — and thus how we engage in much of social action. Essentially Marxian in origin, this insight generates much of the current effort to apply critical theory and deconstruction to discourse and institutional language — for example, in legal theory, in studies of race/gender/other forms of social inequality, and so forth. We continue to explore the related notion of 'linguistic ideology' below.

In their agency as vehicles of manipulations of powers, all linguistic interactions contain an inherently *political* dimension. This may seem a far cry from the philosophically elegant formulations of Tarski and Carnap, but is an unavoidable conclusion if one indeed follows the intellectual heirs of Jakobson, mainly Silverstein. Note, however, that metalinguistic activity and awareness do not necessarily entail a true realization of language's performativity and other systematic pragmatic characteristics. Metalinguistic awareness is not an epiphany — nor does it guarantee that metalinguistic representations correctly express language's true nature. Indeed, Silverstein has tellingly critiqued the 'drive for reference' that pushes speakers and scholars to understand all speech in semantico-referential terms, thereby failing to grasp language's performative functions as well as its ideological structure. Thus the 'distancing' aspect of complex linguistic manipulations such as translation — the first step towards metalinguistic awareness — evoke, but do not in themselves assure, a clearer and true realization of language's nature. We turn now to a more detailed account of the complexities of metalinguistic structure, activity, and awareness in actual social settings, using linguistic analyses and/or empirical studies.

4. Linguistic/empirical studies of metalinguistic structure, activity, and awareness

In recent years, a number of sociolinguists and linguistic anthropologists have studied the role of metalinguistic awareness in filtering the effects of social structure on language use and form. This work carries forward Bahktin's earlier concern with the social functions of 'speech genre', and also brings linguistic specificity to the work of social theorists such as Pierre Bourdieu who have drawn attention to the power dynamics at work in discourse.

For example, in an article on Warao narratives, Charles Briggs (1993b) traces the quite different metapragmatic frames surrounding three renditions of the same narrative, told by the same speaker in differerent settings. Briggs traces a range of relationships between metapragmatic frames, metalinguistic awareness, and social functions of discourse. In the most formal and socially-valorized kind of telling, the narrator insists upon a monologic structure that holds the floor against all challenges. This sets the metalinguistic signalling surrounding the actual telling of the story off as quite separate from the metalinguistic frame of the story itself — the reported event. Silverstein (1993) calls this kind of separation 'nomic calibration' between the metapragmatic structures of the story-telling (the 'signaling event') and the story (the 'textualized event-structure'). This form of calibration minimizes overt metalinguistic signalling and awareness, and occurs in the most formal or ceremonial performances. By contrast, Briggs describes a more 'dyadic' telling of the same story, in which a second speaker participates actively in the performance. Here the metapragmatic frame permits far more overt recognition of the powerful effect of the performance and context upon the story's structure (Silverstein's 'reportive calibration'). Finally, Briggs presents an example of an 'acquisition-oriented' performance, in which the narrator's goal is to help younger men learn to tell this story correctly. By contrast with monologic performances, this form of narrative contains maximally explicit metalinguistic signalling:

> While the performance itself recedes into the metapragmatic background, as it were, in monologic narration, both the ongoing performance and the process of narrating constitute the metapragmatic center of acquisition-oriented examples. Elements of form, function, and narrative content are all taken up in turn by explicitly metapragmatic discourse. (Briggs 1993b: 202)

As Briggs points out, this is an example of Silverstein's 'reflexive calibration', in which the contexts of the current telling and the story told merge. In each case, Briggs traces a strong connection between the degree of explicitness of metalinguistic signalling, and the social contexts and power relations in play (on connections between metalanguage and social structure see also Bauman 1983; Hanks 1993; Philips 1998a, 1998b).

At an even broader level, Richard Parmentier has demonstrated the way in which complex interplays of metalinguistic signalling and awareness affect the production and reception of political speech (1993). In particular, he tracks the metapragmatic structuring of a political speech given by a high-ranking Belauan chief, at a moment of challenge to the older system of chiefly authority. This challenge was enacted in and through metalinguistic markers signalling disrespect and demanding deference — respect that was at once linguistic and social. Interestingly, despite the successful construction of an intricately-structured speech that powerfully mirrored, indexed, and enacted a reassertion of chiefly authority, an unintended alternative metapragmatic interpretation arose. This alternative interpretation looked to the anchoring of the entire speech in a setting that itself challenged traditional chiefly power (a democratically-elected municipal council), with attendant metalinguistic signals that undermined the impact of the speech (for example, the chief had to ask permission from a magistrate to get the floor, and used a form of speech that itself violated traditional norms). Here dynamics of reported speech, metapragmatic structure, and divergences in metalinguistic awareness not only signal and perform aspects of social structure; they in fact shape an event that is one turning point in a process of social change (see also Banfield 1993; Irvine 1998; Mertz 1989; Silverstein 1985a).

In her recent linguistic ethnography of disputing in a Kenyan Islamic court, Susan Hirsch (1998) provides an exemplary analysis of how metalinguistic structuring and awareness play an integral role in broader social shifts. Her book documents the crucial role of metalinguistic ideologies in the struggles over gender roles being played out in Kadhi's Court:

> […] the ideological level of language plays a significant, though largely underrecognized, role in the construction and transformation of gender […] In court, the production of the […] ideologies described above has directive force in shaping interaction […] The force comes in part because the ideologies operate not only through explicit statements that propose moving the metapragmatic frame away from stories but also in more implicit ways that are displayed through the structure of stories and reported conversations. (Hirsch 1998: 234)

Thus women bringing claims to court must operate against a backdrop that associates women's speech with storytelling and men's speech with authoritative utterances that overtly frame and interpret stories at the metalinguistic level. Women are also disadvantaged by a dominant linguistic ideology that casts suspicion on attempts to air family problems. Nonetheless, Hirsch demonstrates how Swahili women are working within and around these metalinguistic frames, using their own powerful metapragmatic techniques to win court battles. These linguistic victories have social entailments; they enact and motivate ongoing shifts in the power dynamics and cultural understandings surrounding gender roles.

As noted by Silverstein in his programmatic essay on the topic, there remain many avenues for future exploration of the precise relationship between metalinguistic awareness and the active participation of language in the constitution of society (1993: 55). Because important dimensions of this relationship have now been delineated with new technical specificity, ongoing research can incorporate consideration of factors such as degrees of denotational explicitness, and forms of pragmatic calibration in developing this genuinely social linguistics (see ibid.).

5. Linguistic ideology

In recent years, there has been a burgeoning literature in the area of 'linguistic ideology' which focuses explicitly on how forms of metalinguistic awareness interact with speech and social power. A full discussion is beyond the scope of this article; we here merely sketch the area. Linguistic anthropologists Kathryn Woolard and Bambi Scheiffelin (1994) have provided a programmatic framework for the study of 'language ideology' or 'linguistic ideology'. Their work outlines a developing paradigm that builds from traditions in linguistic anthropology — particularly Silverstein's work on linguistic ideology (1979, 1985a) — and research on contact among languages in educational and other settings (see Heath 1989; Hill 1985; Woolard 1989), among other areas, to focus upon the social concomitants of metalinguistic conceptualizations. As Woolard summarizes it, a focus on linguistic ideology "implies a methodological stance, a commitment to consider the relevance of social relations, and particularly of power relations" (1998: 10). At times, this focus leads researchers to focus on overtly-stipulated ideas about how language works, while at other times, scholars may focus on the assumptions about language implicit in speakers' talk (see, e.g., Gal 1993; Kroskrity 1998; Philips 1998b). Some studies contrast speakers' overt typifications regarding their own language use with their observed linguistic practices (see, e.g., Irvine 1998), and some researchers combine analysis of overt and tacit linguistic ideologies in studying the nexus between language, power, and social change (see, e.g., Hill 1995, 1998; Silverstein 1985a).

Much of this work demonstrates the importance of linguistic ideology as a point at which language and social structure meet. For example, Gregory Matoesian's exacting linguistic analyses have specified in minute detail the ways in which language ideologies surrounding law and gender contribute to the silencing of rape victims in U.S. courts (1993, 2001). Susan Philips has demonstrated that ideologies regarding the relationship between legal texts and spoken practice in court have helped to conceal the raw political input to criminal court procedures (1998a). James Collins (1996) and Elizabeth Mertz (1996, 1998a, 1998b, 2000) have outlined how linguistic ideologies surrounding primary and law school education in the U.S. embody and reproduce social power. A growing interest in the metalinguistic structuring of text has lead to creative theories of the social processes surrounding textuality (see, e.g., Briggs & Bauman 1992; Hanks 1989; Janowitz 1993; Yovel 2001a). And leading anthropological linguists, along with other scholars concerned with language, continue to develop our understanding of linguistic ideologies through careful ethnographic and theoretical research on this meeting point between language and social power (see, e.g., Blommaert 1999; Cameron 1985, 1995; Collins 1998; Gal & Irvine 1995; Joseph & Taylor 1990).

6. Awareness and intentionality: Cognitive and developmental approaches to metalinguistic activity

How is metalinguistic awareness connected to the development of language skills in general, and of specific language skills — e.g., writing, bilingualism, self-correcting ability — in particular? Under the heading 'cognitive approaches' to metalinguistic awareness we shall briefly discuss a growing body of work that explores the relations between metalinguistic capacities and both basic and complex language skills ('complex' here designates linguistic manipulations beyond the generative structure of language acquisition). Many of these approaches share similar suppositions and concerns, as they respond to the growing body of evidence that connects metalinguistic awareness with the development of language skills (e.g., Ehri 1979; Gombert 1992; Francis 1999). For instance, they are concerned with the question of awareness in the sense of conscious metalinguistic manipulations (as opposed to metalinguistic functions that neither command nor enjoy a special conscious performance, mingled as they are with linguistic performance). They also focus on the question of what stands as metalinguistic knowledge as opposed to linguistic knowledge. And perhaps the most significant of all, they explore the social, cultural, and political aspects of developing metalinguistic awareness, capacity, and skills, in relation to (and perhaps as opposed to) standard approaches to language acquisition.

When examining these and other emerging bodies of work, it is important to keep in mind the distinction between methodology and subject-matter. Many (but not all) cognitive studies of metalinguistic awareness and metalinguistic performance examine linguistic performances where the linguistic apparatus is more observable than elsewhere. However, 'predicting' or inferring linguistic awareness from performance can cause difficulties. Several research programs assume that metalinguistic awareness of some sort is required for more complex discursive and metadiscursive performances. Such, for instance, is the assumption underlying Markman (1979), Flavell (1981), Flavell et al. (1981), who studied children's ability to evaluate the comprehensibility of instructions and stories. Pratt & Grieve (1984: 9–10) warn that

> [t]here remain conceptual and empirical problems in ascertaining the exact relationship between knowledge or awareness of aspects of language and the influence of this awareness on performance. The development of awareness of language […] does not necessarily entail its application to monitoring the use of language in all contexts. For example, in a referential communication task, children may be aware that a good message should be unambiguous and should provide a listener with a clear description of the referent in question. However, there are many occasions when they do not apply this knowledge, and produce messages which remain ambiguous. Consequently, within the cognitive domain there remains a major question concerning the nature of the relationship between awareness and monitoring performance.

Some literature thus discusses metalinguistic 'skills' or 'competence' instead of 'knowledge', the former two presumed 'manifest' while the latter being 'inferred'. The theoretical problem raised by Pratt and Grieve seems nevertheless to apply to most cases.

With this caveat in mind, we can note that awareness of language seems more evident when higher language skills are involved, such as learning a second language, learning to write, or performing complex rhetorical manipulations. That does not necessarily mean that metalinguistic awareness does not play a significant role in language acquisition and other relatively basic processes (Schulz & Pilon 1973; Gleitman, Gleitman & Shipley 1972); it only means that demarcating linguistic and metalinguistic performances in basic linguistic skills may prove more difficult. What researchers look for, initially, is

> [t]he gradual shift of attention from meaning to structure in tasks requiring deliberate control over language forms… the ability to decenter, to shift one's focus from the most salient attributes of a message (its meaning and contextual setting) to structure (the ordinarily transparent vehicle by which meaning is conveyed). (Ryan et al. 1984: 157).

Two related qualifications (or clarifications), broadening the scope of metalinguistic functions, should be made to this definition: first, that metalinguistic awareness does not entail 'deliberate' action, although that is where it is perhaps most noticeable; second, as this article emphasizes, performative metalinguistic functions shape and frame discourse in modes that cannot be reducible to the semantico-referential sense of 'meaning' that much of 'object-language'-oriented linguistics seems to ascribe to 'messages'.

The second clarification to the 'cognitive' heading is that 'psycholinguistic' or 'developmental' approaches should absolutely not be understood to express a Cartesian, monological perspective on language, and do not stand in strict contrast to 'sociolinguistic' or 'communicative'. Indeed the communicative and intersubjective aspects of metalinguistic talk have been stressed already by Jakobson (1960). However, later authors have questioned the Jakobsonian position, according to which metalinguistic talk is in some sense independent from the sender and the receiver and is used to externalize their shared knowledge of a code whose homogeneity has come under powerful critique (see Kerbrat-Orecchioni 1980). We shall now briefly go over a few paradigmatic cases of 'cognitive' metalinguistic awareness research.

6.1 Metalinguistic activity in learning to write

In summing and commenting on different approaches to the study of the role of metalinguistic awareness in learning to write, Camps & Milian (2000) seem most comfortable with the Vygotskian interactive perspective (also explored from different vantages by Greimas 1987, 1990; Silverstein & Urban 1996; Blumberg 1998; Derrida 1977.) In language, Vygotsky recognized the capacity to draw away from the immediate communicative context, through decontextualization, towards abstraction and reflection through reiteration and writing. As this happens, some contextual elements become verbalized and as such integrated in the text in a process that Silverstein & Urban (1996) refer to as a 'natural history' of discourse. Thus portions of 'non-readable' context (the singular frame of any communicative event, in which discourse is embedded) go through a semiotic transformation as they are recontextualized — now as text or 'co-text' to originally processed discourse — in a new social, historical, and cultural context. Some language mechanisms, such as quotations, are more transparent to this process of 'entextualization' than others, such as reported speech (see Briggs & Bauman 1992 on this and other concepts related to the formation and recontextualization of text). Nevertheless speakers use metalinguistic indexicals and deictics to signify their awareness of this process: e.g., parenthesis (with or without an indexical such as 'X said:', which are sometimes incorporated into speech by use of appropriate body gestures (such as the "parenthesis" gesture with two fingers of both hands)). There is something even more immediately metalinguistic about writing, in that the linguistic apparatus becomes an artifact, and as such the object of talk, study, and reflection. And, according to Silverstein & Urban's position, contextualization — a core metalinguistic function — comes 'naturally' as the linguistic tool allows ever more complex modes of forming texts and thrusting them in new contexts.

6.2 Metalinguistic awareness in young children and school children

Two of the major interdependent questions propelling metalinguistic awareness research in children are: (1) whether metalinguistic awareness and metalinguistic abilities are part of linguistic competence, and (2) if they are not, how are they developed? Both questions raise conceptual and empirical concerns. While studying metalinguistic awareness in children, some research programs (e.g., Tunmer et al. 1984: 13–14) insist on distinguishing 'genuine' MA from the concepts of generative grammar, such as tacit knowledge (the unconscious knowledge of a language's system of rules that determine grammatical acceptability, that underlies the Chomskian concept of linguistic competence) or linguistic intuition (which unconsciously underlies all linguistic performance). Nevertheless, linguistic intuitions, such as those constraining phonological performances of newly-encountered words or those involving grammatical acceptability surely imply metalinguistic abilities, and the demarcation between 'competence' and 'metalinguistic awareness' may seem more difficult than postulated by Tunmer & Herriman. Grammatical acceptability intuitions, such as studied by Gleitman et al. (1972) (children aged about 30 months were asked to judge sentences 'good' or 'silly') and de Villiers & de Villiers (1972), were considered by those researchers to manifest a metalinguistic ability. However, the question of how that ability was acquired — as part of Chomskian competence or in a separate or complementary cognitive development — can be argued either way. Most recent efforts tend toward the separate channel (Hakes 1980; Birdsong 1989; among others). Hakes' position, unsurprisingly influential among Piagetians, is that

> metalinguistic abilities are are different from, and emerge later then, the abilities involved in producing and understanding language… their emergence is the linguistic manifestation of the cognitive developmental changes which Piaget has characterized as the emergence of concrete operational thought. (Hakes 1980: 2)

According to Hakes, metalinguistic abilities manifest between the ages of 4 and 8 years (ibid.)

Using less rigorous Piagetian frameworks, some research applies a socio-cognitive approach with easily-recognized Vygotskian roots, according to which children's metalinguistic awareness is constructed intersubjectively, constantly (re-)negotiated with the linguistic environments that they encounter, and within which they are required to perform. The metalinguistic awareness is not examined solely in psychological terms pertaining to an individual, nor merely as a social characteristic of linguistic performance constructed through social interaction, but as a mediating framework for interpretation and peformance in which "social" and "cognitive" aspects of linguistic action necessarily interrelate (Sajavaara et al. 1999).

There is a rich tradition of linguistic scholarship in this more social/Vygotskian framework that owes its vitality to researchers such as Hickmann (1993); Schieffelin (1990); Ochs (1988); Wertsch (1985); Sawyer (1997). This scholarship traces children's developing awareness of both metalinguistic devices and of the social world constructed and indexed in metalanguage.

There is, additionally, interesting research on the role of metalinguistic awareness in cognitive development, and on metalinguistic performance and bilingualism — which, while beyond our present scope, is worthy of attention from those interested in metalinguistic awareness as well. Current research in all areas is increasingly emphasizing the important role of metalinguistic awareness in the acquisition and use of language from early ages — and of the social embeddedness of this process.

7. Conclusion: Metalinguistic creativity, awareness, and the social structuring of communication

Across multiple arenas, then, we see a convergent interest in the role of metalinguistic structure, awareness, and use. This interest is fueled by growing evidence that metalinguistic function and ideology exert a great deal of influence on language, at the same time as they form a crucial nexus with social processes. Thus both linguists interested in the structure and use of language, and scholars interested in studying social change and power, can find an exciting meeting-ground in the study of metalinguistic awareness.

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Perception and language

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1. Overview and introduction

In the following essay, empirical investigations and theoretical treatments of the relationship between perception and language are reviewed from a broadly cognitive science perspective. The first part of the review examines the idea that the content of perceptual experience can be shaped or modified by substantive features of language such as the characteristics of the lexicon. It is concluded that although linguistic modification of perception is theoretically possible, and readily compatible with several current theories of perceptual representation, the data suggest that such modification occurs only in marginal cases. Recent studies favour the view that language is most likely to influence cognition in the absence of perceptual constraints. The second part of the review considers the structural relationship between language and perception within a framework for cognition largely based on neuropsychological evidence. From this viewpoint it seems likely that much perceptual information never makes contact with the mechanisms underlying language processing or conscious awareness. Even some aspects of language use are apparently influenced by perceptual information that is not available for articulation.

Understanding the relationship between language and perception involves consideration of two superficially separate issues:

a. *Interactions at the level of content* — how is perception affected by the features of the particular utterances a speaker uses, and to what extent are the characteristics of language governed by the substance of perceptual experience? This set of issues is firmly centred around long-standing debates such as **linguistic relativity** and **linguistic determinism**. Much of the early research on perception/language interactions was conducted in the absence of any theoretical understanding of cognition, or even in an intellectual climate in which the idea of abstract cognitive processes was rejected. As a result the extent to which research evidence is theoretically interpretable is inevitably restricted.
b. *Interactions at the level of structure* — how do the linguistic and perceptual information processing systems interface with one another? To what extent are linguistic codes used in processing perceptual information, and what aspects of perceptual information become available for encoding and articulation in language? This set of issues is more recent and has been given new salience by attempts within cognitive psychology and the neurosciences to describe the linguistic and perceptual systems as physically realisable (and biologically realised) mechanisms.

2. Relativity and determinism

The study of the relationship between language and perception developed from philosophical debates over the relationship between language and thought. The first real attempts to bring empirical evidence to bear on this question were made towards the end of the nineteenth century. Gladstone (1858), the English statesman and classical scholar, concluded from confusion and inconsistency over the use of colour terms in ancient texts that the Homeric Greeks were sensitive to contrast differences but did not have a fully developed ability to perceive colour. After examining a wider range of texts and colour terms, Geiger (1880) claimed that there was a definite temporal sequence underlying the development of colour vocabulary, related to the order in which discriminative capabilities evolved. Magnus (1880), a German opthalmologist, attempted to separate the question of vocabulary from that of perceptual ability by collecting lexical and perceptual data from 46 distinct ethnic groups. Materials for testing colour vision were sent to missionaries and colonial officials to collect data from non-European samples. The methodological pressure to transmute questions about the relationship between language and thought into questions about the relationship between vocabulary and perception became overwhelming with the rise of behaviourism to ascendancy in psychology and linguistics. Interest in these issues was given new impetus by the theories of linguistic determinism and linguistic relativity developed by Sapir and Whorf.

An influential experiment by Carmichael, Hogan & Walter (1932) showed that verbal labels attached to ambiguous drawings affected later recall. Similarly, Santa & Ranken (1972) showed that subsequent recognition of nonsense shapes is aided by pairing them with an arbitrary verbal label. Such studies have been interpreted to imply that perception intrinsically involves the linguistic encoding operation that is shown to affect memory. It is at least as likely however, that the memory requirement induces a linguistic coding operation that is not required by perception *per se*. Most experimental studies of the language-thought relationship confined themselves to the domain of colour vocabulary and the perception of colours. Linguistic relativity was treated as a methodological convenience that enabled linguistic determinism to be investigated. Linguistic division of the colour spectrum was believed to be arbitrary. If language determines thought, differences in partitions of the spectrum by different languages should be mirrored by differences in colour discriminability. Between-category discriminations should be easier than within-category discriminations. When such perceptual differences failed to emerge, attention was turned to memory for the discriminated colours. For example, Brown & Lenneberg (1954) reported that coloured objects are remembered more easily if they correspond to readily codable colours mapping onto simple colour names. Lantz & Stefflre (1964) restored the language-perception connection by arguing that memory success was determined by the communication accuracy enabled by the linguistic encoding of colours.

Berlin & Kay (1969) reasserted the thesis first proposed by Geiger, that the order in which colour terms are added to the vocabulary of a language followed a specifiable set of rules: If a language has two colour terms they will be 'black' and 'white'; if there is a third tem it will be 'red'; the fourth, fifth, and sixth terms will be 'yellow', 'green', 'blue' (though the order in which the three are added is variable). If there is a seventh term it will be 'brown'; The eighth, ninth, tenth, and eleventh terms will be 'purple', 'pink', 'orange', 'grey', etc. Berlin & Kay also claimed that the best instances of basic colour terms called the 'focal colours' are constant across languages. Subsequently, Berlin & Kay's work has received considerable criticism. For example, it is claimed that of the 20 languages studied by Berlin & Kay, information on 19 came from bilingual speakers living in San Francisco (Harley 2001), and that the criteria Berlin & Kay used for identifying basic colour terms were unsatisfactory and inconsistently applied (Hickerson 1971; Michaels 1977). Support for Berlin & Kay's position has come from Heider's work (1972) on the Dani of New Guinea. The Dani have only two colour terms in their own language, but they learned invented names for focal colours more easily than for non-focal colours, and could also remember instances of focal colours more easily than non-focal colours.

The evidence from studies using focal colours now seemed to demonstrate that the colour spectrum, far from being open to arbitrary segmentation by the categories of language, was biologically fixed and universal. Early studies had obscured this fact by concentrating on cross-linguistic variation between colour boundaries, whilst ignoring agreement on focal colours and best instances. It is particularly striking that the first six focal colours of the Berlin & Kay system (black/white, red/green, blue/yellow) correspond to the three opponent processes underlying the physiology of vision and directly correspond to "the six most sensitive points of the visual system" (Harley 2001: 86).

The evidence that the ability to discriminate colours is identical across all humans without pathology, and is determined by the biology of the visual system rather than language or culture has not gone entirely unchallenged. Lucy & Shweyder (1979) argued that the colour samples used by Berlin & Kay and Heider for focal colours were more physically discriminable than the non-focal colour samples. They reported that when this artefact was corrected, focal colours were not remembered better than non-focal colours. Davidoff, Davies & Roberson (1999a,b) compared memory for colour samples that cross colour boundaries with memory for samples that do not, in English speakers and Berinmo participants from New Guinea. English speakers recognise a 'blue'/'green' boundary, whilst the Berinmo do not. Berinmo participants make a distinction between 'nol' and 'wor' which does not correspond to a category boundary in English. For both groups there was a memory advantage for cross-boundary distinctions compared with within-category distinctions. Hunt & Agnoli (1991) have sympathetically reviewed the 'Whorfian hypothesis' from a 'cognitive psychology perspective', concluding that the speed and efficiency of cognitive operations is probably affected by the characteristics of lexical items. However, the modest effects that are now said to be demonstrated by evidence contrast strikingly with the bold claims that originally triggered debate.

2.1 Perception, language and higher-order cognitive processes

The accumulated evidence suggests that there are both biological and linguistic constraints on memory for colours. The results of several decades of investigation in the laboratory and the field have shown small and indirect effects of lexicalization on perception mediated by attention and memory, but more notably, have reversed the earlier assumption that colour perception is a domain within which effects of language are likely to be prominent. Boroditsky (2001: 2) has recently suggested examples of "domains that appear more likely to reveal linguistic differences than such low-level domains as colour perception". These are: cross-linguistic differences in the object-substance distinction in Yucatec Mayan and Japanese (Gentner & Imai 1997; Lucy 1992); effects of grammatical gender distinctions in Spanish (Sera, Berge & Castillo 1994); cross-linguistic differences in spatial thinking (e.g. Bowerman 1996; Levinson 1996) and evidence suggesting that language influences conceptual development (Markman & Hutchinson 1984; Waxman & Kosowski 1990). Boroditsky argues that abstract domains such as time are more likely to be influenced by language, either because unlike perceptually based concepts they do not developmentally precede language, or because "language is most powerful in determining thought for domains that are more abstract, that is, ones that are not so reliant on sensory experience" (Boroditsky 2001: 19).

Gentner & Boroditsky (2001) also argue that the effect of language should be "most apparent in the conceptualization of relations (typically encoded by verbs and spatial prepositions) as opposed to objects. Whereas object-concepts are easily individuable from perceptual experience, learning the extent and generality of a relational concept requires considerable experience with language" (Boroditsky 2001: 19). The view that language shapes perceptual experience is rapidly being replaced by the view that "language can be a powerful tool for shaping abstract thought. When sensory information is scarce or inconclusive (as with the direction of motion of time), languages may play the most important role in shaping how their speakers think" (Boroditsky 2001: 20). In support of this claim Boroditsky (2001) has reported evidence that bilingual English/Mandarin speakers use spatial metaphors drawn from Mandarin when thinking about time, even in English. A somewhat different take on the debate appears in the view of Slobin (1996) that language may influence thought during 'thinking for speaking'. Language may force us to attend to some aspects of the world by making the distinctions to which they are relevant grammatically obligatory. Again, the expectation that lexical features of language will directly influence perceptual experience has been abandoned, being replaced here, by the claim that *grammatical* features of language will influence perception via attentional processes.

Psychologists primarily interested in cross-linguistic differences in thought appear to be rapidly abandoning the view that language can substantially influence 'basic' visual perception. Pylyshyn (1999) clearly articulates the reason: "although what is commonly referred to as 'visual perception' is potentially determined by the entire cognitive system, there is an important part of this process which […] we will call *early vision* — that is impervious to cognitive influences" (Pylyshyn 1999: 341). Pylyshyn goes on to make the more radical claim that perceptual processes are in general *cognitively impenetrable*, and thus generically unsusceptible to linguistic influence. Pylyshyn points out that there is now a good deal of evidence for two perceptual systems: a *ventral stream* which supports the conscious identification of objects and *a dorsal stream* "tuned for […] 'vision for action' " (Pylyshyn 1999: 347). The latter system may indeed be cognitively impenetrable, and almost certainly does not require consciousness. (This issue is examined further in Sections 3.2, 3.4 and 3.6 below)

Barsalou (1999) has developed a theoretical approach leading to similar conclusions. He argues that the consensus view of cognition assumes that information is represented as *amodal symbols* "an amodal system transduces a subset of a perceptual state into a completely new representational language that is inherently nonperceptual" (Barsalou 1999: 578). Within an amodal symbol system "thought is assumed to be analogous in many important ways to language. Just as language processing assumes the sequential processing of words in a sentence, so conceptual processing is assumed to involve the sequential processing of amodal symbols in list-like or sentence-like structures" (*Ibid*.: 579). The inter-translatability of language and perception via amodal symbols obviously allows direct linguistic modification of perceptual content. Barsalou rejects the idea of cognitive processing based on amodal symbols, arguing instead that "cognition is inherently perceptual, sharing systems with perception at both the cognitive and neural levels" (*Ibid*.: 577). Barsalou allows for perception without awareness by arguing that a "perceptual state contains two components, an unconscious neural representation of physical input, and an optional conscious experience […] On later retrievals this perceptual memory can function symbolically, standing for referents in the world, and entering into symbol manipulation (*Ibid.:* 578). It would seem that the preservation of perceptual information via a distinctive form of encoding at all levels in the cognitive system would make modification of perceptual content by language rather unlikely.

A number of other investigators have recently begun to make the case for a quite different relationship between perception and cognition. Ballard et al. (1997) argue for a cognitive system within which perception and symbols must be at least indirectly linked because "the momentary disposition of the body plays an essential role in the brain's symbolic computations. The body's movements […] provide an essential link between processes underlying elementary perceptual events, and those involved in symbol manipulation and the organisation of complex behaviours" (Ballard et al. 1997: 723). On very similar grounds, Stoffregen & Bardy (2001) have denied the existence of independent senses. The nub of their case is that perceptions of the world must be cognitively modified to take into account movements made by the perceiving organism. Because "behavior produces changes in the structure of multiple forms of ambient energy […] it must be concluded that perceptual systems do not function independently" (Stoffregen & Bardy 2001: 196). Stoffregen & Bardy believe that observers are not "separately sensitive to structures in the optic and acoustic arrays but, rather propose that observers are directly sensitive to patterns that extend across these arrays, that is to patterns in the global array" (*Ibid.*: 211). This analysis implies that a cognitive representation of the global array, that is potentially liable to linguistic influences, precedes the construction of the representations associated with particular senses.

Perhaps most radical of all is the view of O'Regan & Noë (2001) that the senses are not structurally independent information channels, but are ways of acting: "We propose that seeing is a way of acting. It is a particular way of exploring the environment. Activity in internal representations does not generate the experience of seeing. The outside world serves as its own, external representation." (O'Regan & Noë 2001: 1). "[V]ision is a mode of exploration of the world that is mediated by knowledge of what we call sensorimotor contingencies […] what *does* differentiate vision, from audition or touch, say, is *the structure of the rules* governing the sensory changes produced by various motor actions, that is what we call the *sensorimotor contingencies* governing visual exploration" (*Ibid.*: 4). Again, this view seems to imply that perceptual experience is a cognitive construct, and as such, susceptible to influences from language.

Schyns, Goldstone & Thibaut (1998) conclude on the basis of experimental evidence that it must be possible for new perceptual and conceptual features to be created during learning. They argue that: "The function of a feature is to detect and internally represent commonalities between members of the same category, as well as differences between categories. Either people come equipped with a complete set of features that account for all present and future categorisations, or, working backwards, people sometimes create new features to represent new categorisations" (p. 16). Schyns et al. draw the implication that "encoding proximal stimuli with new feature affects the perceptual appearance of the distal object" (p. 16).

One effect of scientific progress is the refinement of metaphors, and eventually their replacement by formal models. Whilst it took centuries to replace memory metaphors such as the *birdcage* and the *wax tablet*, metaphors for the relationship between language and thought (Bruner, Goodnow & Austin 1956) such as the *mould* (public language shapes thought) and the *cloak* (public language is shaped by thought) seem antiquated after only fifty years. This is mainly because of rapid growth in our understanding of visual perception. Perception can no longer be regarded as a proxy for 'thought', but as a complex system in its own right having unique relationships with action, extra-linguistic cognitive processes and language. The evidence makes it unlikely that perceptual information is necessarily or routinely encoded in a linguistic form, and indeed, the perceptual data that underpins action, as opposed to recognition and identification may never become available for articulation. There has been a recent resurgence of theories that posit some kind of global or amodal cognitive representation, and such systems are certainly compatible with direct effects of language upon perception. The brute fact is however, that a hundred years of searching for such effects have resulted only in indirect and marginal 'influences'. It now seems more pertinent to ask how cognition might be structured in such a way as to explain why perception is so little affected by language.

3. Structural constraints upon cognition

There is abundant phenomenological and behavioural evidence of a two-way informational transfer between perceptual mechanisms and language processes. People can describe in words what they are currently sensing, and language can be used to change what they perceptually process, and the manner in which they interpret it. This is not a happy evolutionary accident. Allot (1981) has helped to elucidate the evolutionary pressures driving the cognitive architecture that has emerged:

> language initially is essentially a means for collaboration […] extending pre-linguistic systems for securing co-ordination of action between individuals of a species. […] It functions by allowing a pooling of perceptions between a number of individuals. […] For language to function effectively in the service of perception, it has to be integrated as closely as possible with perception; […] thus there has to be a close integration between the structure and contents of perception and the structure and contents of language — and since perception comes before language (visual perception is an inheritance we share with all animals) and is the more vital activity to serve the needs of action, the structure and contents of language must have been derived from and be dependent on the structure and contents of perception. (Allott 1981: 4)

Allott also draws attention to a third important member of the cognitive pantheon: "language developed in the service of perception; and perception, as a general animal function, developed as a means of increasing the effectiveness of bodily action and so improving the chances of survival. For language and perception to be most effective, they must, in their turn, neurologically and physiologically, be closely integrated with the organisation of bodily action" (*Ibid.*: 4). "Vision and action proceed together, mutually modifying each other; language itself is action, can refer to action, can cause action and can be modified in its form from moment to moment by the train of visual perception" (*Ibid.*: 15).

Arguments such as those used by Allott draw attention to the fact that perception and language are not free-standing systems that have been independently engineered and connected together as an afterthought. *Perception is the process by which organisms gain* *knowledge about the world outside their central nervous systems*. This claim has a number of important implications:

a. Perceiving agents are *organisms*. This term implies that perceiving agents are biological systems that have developed via evolutionary processes. The propensity to accumulate knowledge can therefore be expected to confer some selection benefit, by for example, enhancing survival probability or opportunities for reproduction. This is an important reminder that knowledge is instrumental, i.e. its value lies in enhancing the adaptive value of action. This implies two principles: **the primacy of action over knowledge** and the **adaptive sufficiency** principle that to count as knowledge it is sufficient that information enhances the adaptive value of action. The latter principle provides a salutary warning of the quixotic character of attempts to construct an epistemology on the foundations of absolutely certain knowledge.
b. Perception is a process of **knowledge** acquisition, not simple response to stimuli, nor mere sensitivity to uninterpreted sensations. This defining feature restricts perception to organisms capable of knowledge manipulation.
c. Knowledge derived from perception is of the world **outside** the organism. This presupposes a realist epistemology of some kind, and hence the rejection of idealist/sceptical philosophies such as those of Plato, Berkeley and Kant, and more recently, Lacan and Rorty. At least a restricted variety of empiricism is also implicit: 'restricted' because it is not directly implied that all knowledge comes from the senses, nor that sensory knowledge has priority over knowledge from other sources. Features (a) and (c) taken together have further implications that may not be obvious. The capacity for perception implies the existence of a system for detecting and processing information. If this system has evolved (or even if it was created) the selection/design process leading to its current form has been one of 'tuning' the perceptual apparatus to real features of the world. Only on this assumption would evolutionary 'refinements' of the system confer adaptive benefit. It follows from this that the structure of the perceptual and knowledge-handling apparatus is itself knowledge rich. It is a familiar point in computer science that knowledge resides in the structure of programs as well as the data processed, but this point is sometimes lost in debates about epistemology. Human knowledge comes from 'slow learning' via evolution, as well as fast learning occurring during the lifetime of an individual. For this reason questions concerning the learned or innate status of human knowledge are bound to be somewhat quixotic in character.

For present purposes, language might be characterized as *a communication system based upon a system of signs, constraints on how signs can be combined together and processes by which signs are related to knowledge and action*. 'Knowledge' itself is not monolithic: knowledge of the current state of the local world is perceptual, but knowledge of past events and future goals comes from memory and knowledge of present feelings comes from consciousness. Understanding the structural relationship between language and perception requires an account of a wider range of cognitive interfaces. To give an example: if a participant in an experiment is seated before a screen and told to 'press a button when a letter appears', **language** is likely to influence **perception** because the verbal instruction can only control **action** via an intermediate effect upon perception. The fact that current behaviour is being regulated by the experimental instructions will normally be available to a human agent via **consciousness**. Use of the term 'interfaces' implies a set of relatively stable units or processing systems with the interfaces providing communication routes between them. The term is not intended to imply a modular structure in a Fodorean sense (Fodor 1983). The units or systems that are interfaced together may sometimes be mappable onto specific brain structures, but in other cases they may be functionally defined and structurally distributed. Sometimes the units/systems may operate with particular sets of symbols and interpretations, but on other occasions their operation might be sub-symbolic or connectionist. Certainly no implication of scale is intended (e.g. that units correspond to 'faculties'), nor should the assumption be conveyed that interfaces are communication links between independent symbol processing systems. At bottom 'interfaces' should be taken to imply no more than relatively narrow bandwidth communication channels between processing systems that have relatively wide bandwidth internal communications.

One final disclaimer: in the discussion below, most attention will be given to propositional aspects of speech, and very little will be said about cognitive processes mediated by subcortical structures. There is good reason for this: little is known about the details of the psychological processes underlying paralinguistic functions such as lexical selection, voice amplitude, intonation contour, or gestural support. At the neuropsychological level, neural connections between subcortical brain structures and the cortex are often diffuse, so hard to trace histologically, let alone to track. To make matters worse, communication of emotion-related information frequently makes use of chemical neurotransmitters, both within the brain, and between the brain and the peripheral musculature (e.g. fear may trigger adrenalin release, and the consequent high arousal may temporarily reduce access to most lexical items other than expletives, whilst increased muscle tension simultaneously increases voice pitch). The consequence is that though perceptual effects upon language may predominantly operate upon paralinguistic aspects of speech and language, there is little compelling evidence that this occurs, and almost no basis for proposing an underlying mechanism. Bearing in mind that the extent of discussion is proportional to what is currently known, rather than what may one day be discovered, we shall now briefly consider some of the relevant cognitive interfaces.

3.1 The language–perception interface

Full linguistic communication is only possible if input can be detected and interpreted. Input can apparently be received via any sensory modality (e.g. hearing, sight, touch) capable of receiving a stable signal that can be identified and re-identified. Sign identification requires current input to be related to previously acquired **linguistic** knowledge. Processing that requires specifically linguistic knowledge appears to occur within one of a number of specialised neuropsychological 'routes' or 'pathways' (one for spoken language, one for written language, one for visual sign language, etc.). Such pathways are associated with dedicated brain areas, and may be selectively damaged or spared by brain injury (Wernicke's aphasia is a well-known example of selective loss or impairment of the speech reception pathway). Sign interpretation additionally requires access to **extra-linguistic** knowledge (though this may be stored in a linguistic format). These two processes appear to be neuropsychologically as well as conceptually distinct. Pathological disruption of sign identification (in conditions such as aphasia and dyslexia) can occur whilst extra-linguistic knowledge remains available for deployment in non-linguistic tasks. Conversely, loss of extra-linguistic knowledge (amnesia) often leaves language perception unimpaired. Some of the extra-linguistic knowledge required for sign interpretation is relatively independent of context, but richer interpretation often requires assumptions about the goals and purposes of the sign originator (pragmatic interpretation). Underlying processes involved in this stage include metaphor interpretation and relevance judgements.

The cognitive processing of non-linguistic perceptual information requires the integration of current sensory data with data stored in memory. There is compelling evidence for a major subdivision between **declarative** or **explicit** memory, on the one hand, and **non-declarative** memory on the other (Squire 1994). Sensory data may be routed to either or both memory systems. If perceptual interpretation is mediated only by non-declarative memory, it will not be available to report procedures requiring awareness of familiarity such as recall and recognition. It will be available to guide physical responses and may be detectable by implicit memory procedures. Some such procedures are linguistic. As a consequence there is now known to be a range of contexts in which registration in declarative memory can be prevented, so that a person has no knowledge of experiencing events that can nonetheless be shown to affect measures of implicit memory. Such anomalous contexts include medial temporal or diencephalic brain lesions, psychological trauma, electro-convulsive therapy, surgical anaesthesia, hypnosis, and subliminal presentation of information. To consider one of these cases in more detail: Block et al. (1991) presented word lists to patients under deep surgical anaesthesia. Post-operatively the patients were unable to recall or recognize the presented items. However, a measure of implicit memory showed unequivocal evidence of retention. The measure used was **word-stem completion** if 'cradle' was one of the presented words, the patient is later asked to complete the word-stem 'cra…'. If the stem is completed with '… dle' more frequently by patients than by control subjects (who may complete more often as 'crayon' or 'crate' for example), then this is taken to be evidence of retention. The clear implications of studies of this kind is that the stream of perceptual information that is available to language processes is a different stream from the perceptual information that guides most non-linguistic, and some linguistic behaviour.

3.2 The perception–action interface

Action is a movement-goal pairing, i.e. a movement initiated to achieve some goal. It is now generally accepted that the control of action by vision involves two distinct information processing sub-systems. These sub-systems are differentiated at both the subcortical and cortical levels. At the subcortical level, retinal information conveyed via **parvo** cells is stable and suitable for the analysis of fine detail, such as the properties of objects. Information transmitted via **magno** cells is transient and more suitable for the detection and analysis of change over time (Livingstone & Hubel 1988; Merigan & Maunsell 1993). Within the cortex the **ventral route** terminating in the temporal lobe is believed to process the kind of 'what' information originating from the fovea of the eye and associated with the subcortical parvo system. Information in this system is appropriate for the detailed featural analysis of static objects. The **dorsal route** terminates in the parietal lobe and processes 'where' information originating from peripheral vision, and concerned with controlling movement and directing eye movements (Mishkin et al. 1983; Baizer et al. 1991; Boussaoud et al. 1996). At the cognitive level of analysis, it is also useful to distinguish between **controlled processing** behaviour that is under conscious control so that current goals and relevant perceptual information can be articulated; and **automatic processing** behaviour that is controlled without the involvement of conscious awareness (Shiffrin & Schneider 1977; Norman & Shallice 1986). Either form of behaviour may be a **closed loop** (Toates 1975), that is, it can be guided by a process of reducing the difference between the current state and a goal state.

3.3 The language–action interface

A special case of an interface between language and action is speech, i.e. action within the linguistic modality. Speech appears to involve closed-loop automatic processing within a dedicated cognitive subsystem. As with language perception, speech may be selectively lost or spared as a result of brain injury or disease (Broca's aphasia is a well-known example of the selective loss or impairment of the speech production pathway). Another special case is that of acting on instructions or following commands. Here, speech perception is followed by actions whose nature is partially determined by knowledge extracted from the prior speech. The consequent actions would seem to be special in no way other than their history. The 'standard' case of the language-action interface is presumably using language whilst acting. Language use and concurrent action are known to reciprocally interfere through competition for general capacity (Baddeley 1990; Reisberg 2001) and through competition for specific resources when tasks compel this (Allport, Antonis & Reynolds 1972; Pashler 1994). A central question in relation to this interface is: which (if any) of the processes and features associated with a current action are available for articulation? This is a question about **awareness** rather than perception, as it seems quite common for agents to perceive a routine action they are carrying out, without being sufficiently conscious of what they are seeing or hearing as to be capable of reporting it. The most useful current framework for understanding the interaction between language and action is probably that of Norman & Shallice (1986). According to their **Supervisory Attentional System (SAS)**, skilled, routinized action is controlled by pre-programmed schemas triggered directly by perceptual information. This **contention scheduling** process is not under voluntary control and does not involve awareness. If automatic processing fails because of contextual novelty, or because circumstances are dangerous, then SAS is invoked, awareness results and actions become fully reportable via language.

3.4 The perception–consciousness interface

Perception can occur without the resulting knowledge becoming available to consciousness. The automatic processing characteristic of skilled behaviours such as driving, is evidently controlled by perceptual information, and yet not dependent upon conscious awareness. The clinical analogue of this phenomenon is known as 'blindsight' (Weiskrantz 1986), and occurs when as a result of injury or damage to the primary visual cortex, individuals are unaware of visual stimulation and consider themselves to be blind. It has now been demonstrated in many such cases (Brent, Kennard & Ruddock 1994) that if patients are required to act upon the visual information of which they are unaware, for example by pointing, or choosing between alternatives, their overt behaviour remains under perceptual control. Marcel (1998) has reported a study in which patients were exposed to words (e.g. 'river' or 'money') of which they were unaware. When subsequently asked to choose between interpretations of ambiguous words, e.g. 'bank' their choices were clearly influenced by the earlier biasing stimuli of which they remained unaware.

3.5 The language–consciousness interface

The relationship between language and consciousness is particularly complex and intriguing, but little understood. It is often assumed that people can describe in language everything of which they are conscious, and are conscious of everything they could potentially describe at any particular moment. Gazzaniga (1988) has argued that left cerebral hemisphere mechanisms responsible for language behaviour seem to be implicated in conscious awareness. However, the inadequacy of introspection as a methodology in psychology shows that the consciousness/describability relationship must fall short of identity; speakers are often painfully aware of their inability to articulate feelings and sensations. There are extremely challenging, if not intractable, problems associated with trying to separately identify what a person is conscious of and what they can describe so that the two lists can be compared. The change blindness experiments recently reported by for example, Simons (2000) and O'Regan & Noë (2001) have begun to suggest that the perceptual scope of consciousness is much more restricted than people generally believe. Reisberg (2001) comments that experiments of this kind undermine the naïve belief that "our perception of the world is relatively complete, without large 'gaps' in what we see. But the results we are considering imply that there *are* gaps. Conspicuous objects directly in front of our eyes are not seen unless we are expending some effort to see them" (Reisberg 2001: 99). It is equally apparent that speakers are not conscious of every aspect of their own utterances, for example many aspects of syntax. If people can speak without awareness of syntax, it seems probable that there are also areas of semantics and pragmatics that are phenomenologically opaque.

3.6 The consciousness–action interface

The cognitive management of most skilled action involves *automatic processing* (Shiffrin & Schneider 1984) using information from *procedural memory,* a subsystem of implicit memory that does not require conscious awareness of retrieval operations. (Squire 1994). Accordingly it is clear that consciousness of the motor components and sensory features that guide action are not essential for intelligent action to occur. A range of clinical phenomena (such as *blindsight*, Weiskrantz & Warrington 1979) and experimental findings (Marcel & Bisiach 1998) have provided paradigmatic instances of action control that is at least partially independent of conscious awareness. It thus seems that language can control perceptually regulated actions, either with the involvement of consciousness (*controlled processing*, characteristic of novice performance) or without such involvement (in skilled behaviour or under unusual experimental or clinical conditions). The evidence suggests that there is a cognitive control route that allows language to substantially modify the way perceptual information is used (in regulating action) that does not require consciousness. There is no evidence as yet, that linguistic actions can themselves be controlled in this way. It is easy to speculate that, for example, *superfluent* speech in association with receptive aphasia (Lenneberg 1967) may be sensitive to perceptual features of the environment, but not consciously controlled or understood by the speaker. Unfortunately, speakers with such disorders cannot enlighten researchers as they are not able to understand enquiries that are put to them.

4. Conclusions

The relationship between perception and language has attracted much interest and research attention. Early research questions were not well formulated and often emanated from incoherent theoretical frameworks. Nonetheless, the accumulated evidence is sufficient to rule out any major effect of language on perceptual experience directly grounded in sensory data. The explosion of research in cognitive neuropsychology, fed by developments in imaging technology, suggests that the human information processing system is functionally subdivided. Neurocognitive compartmentalization explains the lack of obvious interactions between the content of language and perceptual experience. At the same time numerous new questions are raised about the extent to which integration occurs, and the nature of the information available to the various subsystems to the extent that they are discrete. At present psychology and neuropsychology are having unprecedented success at identifying systems and interactions between systems of mid-range complexity (for example: visual perception and action control). It seems highly likely that rather than occurring at intermediate complexity levels, the major points of convergence between language and perception will prove to be at much lower levels (e.g. effects of emotion-related diffuse activation and neurotransmitter release upon non-propositional language) or at much higher levels. For example, top-level cognitive operations such as goal-setting must be influenced by what is available in the perceptual environment. Propositional speech is one kind of instrument that can assist in achieving goals once they are set. Conversely, the use of language by one agent to co-opt another into joint goal seeking will clearly have a profound effect upon what perceptual information is relevant, and hence attended to. There is good reason to believe that cognitive macro-processes of this kind, in which action planning, language and attentional processes are simultaneously implicated, do occur, and have a specific association with systems controlled by the prefrontal cortex of the brain. At the time of writing however, researchers have provided more promissory notes than satisfactory explanations.

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Psycholinguistics

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Anyone who is interested in finding out what the state of the art is in a particular science wants the answer to a limited set of questions. What are the major goals of this discipline? Which theoretical models are generally accepted on the basis of the available research data or are, at least, at the top of researchers' minds when thinking about their discipline? At a less general level, which are the most pressing questions on the current research agenda, those where the majority of scientists turn their attention to? Finally, how do researchers in this discipline collect their data, i.e., which methods and techniques do they have at their disposal for studying the phenomena they are interested in?

For instance, people who like to learn more about physics would be interested in the general insights physicists hope to achieve. They would also want to be informed on the theoretical models that current-day researchers adopt on the structure of matter, the universe, etc. Next, they would like to be informed on the questions that matter most to current-day physicists and, hence, determine the recurring themes at conferences and in scientific journals. And, finally, they would be interested in finding out which methodologies and techniques researchers use to collect the data their theories are based on.

The goal of the present chapter is an attempt to answer these questions for the field of psycholinguistics. However, before tackling each of these questions in turn, I will backtrack a few decades and give a short sketch of how psycholinguistics became a research domain of its own, at the intersection between linguistics and experimental psychology (Section 1). After that, I will briefly describe the general goals that psycholinguists try to achieve (Section 2). In Section 3, I will give an overview of the dominant model types that flourish in the field and form a theoretical divide between researchers. Next, I will offer a description of the general methodological paradigms that researchers rely on and their underlying rationale (Section 4). Then, I will focus on the research techniques that are most frequently used in the methodological arena of experimentation (Section 5). Taken together, these sections offer a broad characterization of the field and form the first part of this chapter.

The second part consists of what I hope to be representative reviews of the specific psycholinguistic research that has been performed with respect to each of the four language skills. There will be a section on written language processing (Section 6), focusing on both perception and production aspects, more particularly, the recognition process of written words (Section 6.1) and the spelling of these words (Section 6.2). This will be followed by a section on spoken language processing (Section 7), where a distinction will also be made between the perception and production aspects of speech (Sections 7.1 and 7.2, respectively). The order in which these four topics are treated does not in any way reflect the relative importance of these four research streams within the discipline, but merely results from my own activity in the field. As I have always been studying the processes of reading and spelling and, hence, am only familiar with the topics in speech recognition and production through journals and conference lectures, I feel more confident starting with written language processing. In the discussion of each of the four research domains, I will focus each time on the important theoretical issues, the techniques that have been used to approach them, and the current answers to these questions or, alternatively, the controversies they have given rise to.

1. The birth, adolescence, and adulthood of psycholinguistics

Lets start with a very general characterization of the field: the purpose of psycholinguistics is to achieve insight into the mental infrastructure that makes language use possible. The fact that psycholinguists ultimately want to find out what makes language use possible is obviously reminiscent of Chomsky's credo (already half a century ago) that the human mind is designed to use language. If we had no species-specific language acquisition device (called a language module by Fodor, 1983) children could never internalize the grammar that is implicitly encoded in the sentences they hear in their environment. Thus considered, psycholinguistics is part of the large Chomskyan legacy, as so many other subdisciplines on the linguistic territory.

Chomsky's impact on the current linguistic landscape can hardly be over-estimated, irrespective of the correctness of either his core proposal that humans are endowed with a mental grammatical template guiding their language acquisition, or his formal methodology for studying language from this perspective. Not only did his view result in a radical paradigm shift in theoretical linguistics and a formal model of language that underwent a series of revisions over time, it also spawned a boost in studies of formal languages (Levelt 1974), an active interest in the search for language universals (Greenberg 1963), the study of language acquisition (Bates 1974; MacWhinney 1975; Snow & Ferguson 1977), and so much more. However, within linguistics itself Chomsky's theorizing not only introduced a novel paradigm for doing research in theoretical linguistics, it also influenced the field by fuelling fierce controversies about the real nature of language. In the wake of these discussions, full-blown novel approaches to language saw the light, such as sociolinguistics (Labov 2006, 2nd ed.), pragmatics (Grice 1968; Brown & Levinson 1978), cognitive linguistics (Langacker 1987) and psycholinguistics (Fodor, Bever, & Garrett 1974). Hence the above claim that the major goal of psycholinguistics was initially inspired by the Chomskyan mentalist approach to language.

However, the first excitement about Chomsky's belief that language provides a window on the human mind, thus allowing linguists to draw the map of the language module in our cognitive system, and especially the initial enthusiasm that some of his proposals might also be relevant for language processing soon dampened. The well-known psychologist George Miller (1962) had been quite positive about the future perspectives when he wrote in an issue of *American Psychologist:* "I believe that one of the best ways to study a human mind is by studying the verbal systems that it uses. Such a program is not only important, but immediately possible." He had done some experimental work along these lines as well (Miller & McKean 1964). However, when a number of experimentalists made it their goal to test the so-called *psychological reality* of a number of key concepts in Chomsky's generative grammar, this time of great expectations came to end within ten years after the publication of Chomsky's ground-breaking book *Aspects of the Theory of Syntax* (1965).

The pioneers in this endeavour, Merrill Garrett, Jerry Fodor, and Thomas Bever carried out a number of important experiments, trying to find out how well the mental processes involved in language use mapped onto the theoretical operations in generative linguistic theory. They did not. In their co-authored classic book (Fodor et al. 1974) their central message was that the major formal operations that are performed on linguistic representations in Chomsky's framework (transformations) did not correspond to the processes that language users mobilize in sentence processing. For instance, sentences that required a longer chain of formal transformations between deep and surface structure in generative grammar at the time did not necessarily take more processing time in behavioural experiments. Hence, George Miller's theory of derivational complexity, postulating such a correspondence, was proven wrong. These and other experimental findings indicated that Chomsky's theoretical notions were merely formal tools for describing, in a technical language, the implicit knowledge structures of language users (e.g., knowledge about sentence complexity), without any commitment to a psychological theory of representation and processing. Hence, they could not be treated as concepts that are isomorphic to language users' actual mental structures or processes in language use. As a matter of fact, Chomsky (1965) himself had warned against such a misinterpretation of his theory:

> "When we speak of a grammar generating a sentence with a certain structural description, we mean simply that the grammar assigns this structural description to the sentence. When we say that a sentence has a certain derivation with respect to a particular generative grammar, *we say nothing about how the speaker or hearer might proceed, in some practical or efficient manner, to construct such a derivation.* These questions belong to the theory of language use – to the theory of performance." (p. 9, my emphasis)

Note that it is ironical to see history repeating itself, albeit with a strange twist. Exactly the reverse error regarding the psychological reality of linguistic analyses was made by (some) theoretical linguists working in the domain of cognitive linguistics. This time some of these linguists themselves rather than experimental psychologists strongly suggested that the outcome of their armchair semantic analyses of a word's polysemy offered a picture of distinctions made in the human mind (for a methodological critique on this line of reasoning, see Sandra and Rice 1995; Sandra 1998).

At any rate, even though early psycholinguistics had its roots in generative linguistics, it soon reached adolescence and became more and more an independent discipline, defining its own research questions. Importantly, this does not mean that all distinctions made in linguistics were suddenly thrown away. In the psycholinguistic study of both lexical and sentence processing, theoretical concepts like morphemes and phrase structures are still used. As a matter of fact, it is hard to imagine how one could study language processing without making reference to the major language elements that have been identified by linguists at all. How could one formulate hypotheses about the role of the elementary building blocks of words and sentences if one cannot make use of the terminology developed by linguists?

This, of course, does not necessarily entail that all psycholinguists work on the assumption that each linguistic distinction is somehow reified in the mind, as an object of representation that plays a role at some level of language processing. Some researchers use the linguistic terminology to make clear what they are talking about, but do not make the additional assumption that each linguistic concept necessarily has a representational status in the language user's mind. As a matter of fact, this is the conviction of many connectionists (see Section 3), who often define a linguistic construct as an emergent property of a processing system that discovers regularities and subregularities in the language data on the basis of its capacity to 'perceive' correlations between several kinds of elements. Notions like 'regularities' (a different concept than 'rules') and 'correlations' indicate that these are statistical approaches to language and its 'units', which sharply deviate from a linguistic perspective. Seidenberg (1987), for instance, rejected the idea of morphemes as independent linguistic objects, defining them as emergent properties instead. In his view, 'morphemes' (in written words) merely reflect the fact that the two letters that cross a morpheme boundary typically have a lower co-occurrence frequency than the pairs of letters within morphemes, which causes emergent patterns in the data. In his later convergence theory (Seidenberg & Gonnerman 2000) morphemes are described as graded phenomena resulting from correlations among orthography, phonology and semantics, i.e., which again betrays a statistical approach.

Despite the fact that many psycholinguists still make frequent use of linguistic terminology and that quite a few also believe that there are mental correlates for (some) linguistic distinctions, one cannot deny that there has been a divorce between the two disciplines. This divorce resulted from the early, naive assumption that psycholinguistics must test the psychological reality of theory-dependent notions, i.e., is a tool for validating or falsifying a linguistic theory. Current-day psycholinguists work on the assumption that it is not their task to test whether a theoretical linguistic framework that is the fashion of the day can be translated into claims about the way in which words and sentences are mentally represented and/or processed. One may wonder whether such a goal is even feasible in principle, as each group of researchers targets quite different goals. Even though linguists studying language may consider language as a window on the human mind, either because they think language is a separate faculty in the human cognitive system or because they believe that language and basic cognitive principles are deeply interconnected, it is not their aim, nor could it be (by definition), to design a theory on how their theoretical distinctions are implemented in the mind, neither in terms of representations nor in terms of processes.

2. Major goals

The preceding paragraph already contained some hints with respect to this issue. We saw that, at a very broad level, psycholinguistics can be defined as the study of what is going on in the human mind during language use. Obviously, this is such a general statement that it is barely informative. Hence, a definition at a much more specific level is required, which I propose to be the following: psycholinguistics is the discipline studying the mental structures and processes that language users rely on (i) when they are confronted with a particular type of language material (e.g., reduced relatives, particular word types), (ii) while being engaged in one of the four forms of language use: speaking, listening, reading, or writing, and (iii) while being in one of the three possible states of language knowledge: a state of language acquisition, the mature state of the experienced language user, or the state of language malfunction or desintegration (the latter being the result of either an innate deficit, e.g., developmental dyslexia, or an acquired brain trauma, e.g., aphasia). Lets make this specific definition more comprehensive by breaking it down into its components.

According to the above definition the discipline can be conceptualized as the collection of cells in a 2 by N by 4 by 3 four-dimensional structure, whose dimensions correspond to the type of mental 'object' in focus (representations vs processes), the type of language phenomenon under study (e.g., lexical vs syntactic structures; there are many, hence, N), the type of language use (the four language skills) and the language user's stage of language proficiency (acquisition, mature, malfunction/desintegration). This gives rise to 24*N different lines of research, making psycholinguistics a very broad enterprise. This picture can be somewhat simplified by leaving out the factor of language proficiency. The study of how children acquire their native language and the study of how a form of language use is affected when part of its neural substrate malfunctions can certainly shed light on properties of the mental infrastructure underlying experienced language use, more particularly, by identifying the nature of the process/representation that eventually evolves into a mature state or by investigating the nature of the process/representation that desintegrates. However, the term 'psycholinguistics' is generally applied to the study of the mental apparatus that supports language use in its mature state. Researchers of language acquisition and language disabilities each form their own community, with its own scientific journals and conferences and with its own study methods, even though they fall under the umbrella of the psycholinguistic endeavour.

This leaves us with three defining factors: type of mental 'object', type of language phenomenon, and type of language use. The latter two factors need no comment, so that psycholinguistics turns out to be the study of the mental representations and processes that are involved when one uses a particular language phenomenon while being engaged in a particular language skill. Hence, the only remaining question is: what exactly is meant by a mental representation and a mental process?

The meaning of the term 'representation' can perhaps best be explained by morphologically decomposing the word into its stem and prefix: re-presentation. Literally, a representation presents something again, in a different form. Taking examples from daily life, one could say that a photograph visually represents a person or scene at one moment in the past. A particularly useful example is music, because music can be represented in a variety of ways. The sequence of musical notes on paper visually represents the sounds of a song in the form of a representational system of visual symbols. The recording of that song in the form of tiny horizontal deviances in the small spiral-formed groove of an old vinyl plate is a representation of that song in a physical code system, which can be mechanically transformed into the audio signal. The recording of the song on an audio cd involves two levels of representation: the deepest level is the physical encoding, in the form of a sequence of pits and 'lands' in the long, extremely small spiral track, a representation that is subsequently transformed into another representational format, that of a digital code. The digital information is not encoded in a simple one-to-one fashion, such that a pit is a 0 and a land is a 1 (or vice versa). Rather a change between a pit and a land or between a land and a pit represents a 1, whereas no change represents a 0. The latter code is finally transformed into the audio signal of the music.

Mental representations (of language in this case) are something similar: they represent the information that has to be stored both in a particular code (comparable to the pits and lands on a cd) and in a particular medium (comparable to the polycarbonade plastic of a cd). Their medium, of course, is formed by the neural structures of the brain. The representational code used at this deepest level of representation is unknown. Whereas people invented the code made up of pits and lands on cd's and, hence, understand it (at least, the engineers do!), the neural code that is used to represent language is the result of biological evolution and is far from understood yet. Hence, psycholinguists' hypotheses and claims with respect to the representation of words and syntactic patterns make no reference to the encoding of language in the neural hardware of the brain (not even in studies where brain imaging techniques are used).

To continue the analogy with the representation of music on a cd, any psycholinguistic hypothesis or theory pertains to a representational level that is comparable to the digital representation into which the physical representation on a cd is transformed, a level intermediate between what can be perceived in the outside world, i.e., the physical signal that must be encoded, and its actual encoding in a physical carrier. For instance, the mental representation of a word is situated between its physical representation in brain tissue (comparable to a song's physical encoding on a cd) and its physical realization in the world (comparable to the physical signal of the song). From this perspective, mental representations have no real existence, as they refer neither to the physical aspects of the linguistic signal nor to its neural representation. They are like representations in a virtual world in-between these two tangible worlds. However, intangible as they are, they are necessary scientific constructs if one wants a vocabulary for talking about language representation at all. By forming a virtual interface between the physical realization of language and its encoding in the brain, mental representations make it possible to discuss representational issues in terms of ordinary words, for instance, by making reference to common linguistic distinctions like phoneme, morpheme, semantic relationship, noun phrase, etc. In order to discover constraints on representations (ultimately the neural ones) one will have to define them in a terminology that belongs to the reality that is being represented and is, hence, understandable.

Thus considered, mental representations are like icons on a modern computer: they form an interface between the world that everybody understands and can describe with ordinary words (e.g., a desktop, a map, a file) and the physical world of the machine that only computer specialists understand. The icons enable computer users to think in everyday terms about the way their computer works without having the slightest idea about the processes of physical memory retrieval and processing on machine codes that are triggered by double-clicking an icon (or feeling the need to understand these technicalities). Similarly, psycholinguists can use mental representations when constructing models of a mental activity, like language processing, without having to understand the physical reality at a deeper representational level.

The virtual nature of mental representations does not in the least devaluate the psycholinguistic enterprise, as the progress that has been made over the past four decades has shown. On the contrary, being framed in the vocabulary of ordinary language, these representations make it possible to formulate hypotheses in terms of concepts that researchers can understand. Thus mental representations drive research that makes it possible to identify constraints on language processing. Once a constraint is identified, each level of representation will have to observe it, as the representation at one representational level is mapped onto a different kind of representation (i.e., it is recoded), while preserving the information it encodes. For instance, when participants' behavior in an experiment (e.g., response speed in some task) reveals that they are sensitive to morphological structure when reading words, this finding indicates that this structure plays a role at a particular level of mental representation and, ultimately, also at the level of neural representation to which the mental representation provides an intelligibe interface.

Given the above definition of a mental representation, it is easy to define the meaning of the term 'mental process'. Mental processes are operations on mental representations. Ultimately, these operations can also be translated into brain processes, although the remark with respect to mental representations can also be made with respect to mental processes. When the processes are described with respect to the virtual in-between level mentioned above, they will be intelligible, as they will make reference to words in our familiar language. Many psycholinguists conceive of a mental process as a procedure that maps one type of mental representation onto a different one.

Thus the above statement that the general purpose of psycholinguistics is an attempt to characterize the mental infrastructure behind language use can now be formulated in a much more transparent terminology. It is the attempt to discover the sequence of mental representations and mental processes operating on these representations when a language user is processing a particular language phenomenon using a particular language skill (e.g., speech perception). For instance, which mental representations and processes mapping one representation onto the other are involved when a reader recognizes a morphologically complex word or a word that has the same form but a different meaning in two languages (e.g., English *room*, which has the same form in Dutch, where its meaning is 'cream')? Which mental representations and processes are mobilized when a reader reads a sentence like *The horse raced past the barn fell* (where *fell* is the verb of the main clause and *raced* the verb of a reduced relative)?

3. Major theoretical models

Psycholinguistic models used to be of the box-and-arrow type, which means that researchers derived from their data a number of plausible processing stages, whose names they used as labels for the boxes in their model, and drew arrows between these boxes, thus indicating that information was transmitted from one box to the other. Such models are obviously nothing more than graphical representations of the representations and processes that are described by the researcher. For that reason they are also called 'verbal models'.

Since the time of easy access to personal computers and their high calculating power, many verbal models have been replaced by computational ones. Indeed, a model is much more powerful if it can simulate experimental data on human language behaviour. When attempting to achieve that goal one is forced to make all one's theoretical assumptions explicit, even those that one has perhaps not thought about but are necessary to build an operational model. Only then, it is possible to translate the verbal model into a computer programme, which can then apply the processes it has been programmed to execute to its input and generate an output. The degree of match between the model's output and the human data is an index of the model's success.

Working from such a perspective can only be beneficial for the advancement of the scientific discipline. As a matter of fact, translating one's theory into a testable model is the normal state of affairs in many sciences. Meteorological models, for instance, are considered successful to the extent that they can predict the wheather for the coming days relatively well on the basis of an algorithm whose critical parameters (temperature, air pressure, etc.) are continually updated on the basis of information from wheather stations around the globe.

Models on language processing differ along three dimensions, each of which can be formulated as a question. (i) What is the nature of the processes that retrieve stored information? (ii) What is the nature of the mental representations themselves? (iii) Does the model leave room for abstract rules, which are by necessity symbolic, as rules make reference to abstract linguistic categories (e.g., *"add –ed to V"* for regular past tense formation of verbs)? I will discuss issues (i) and (ii) together, for the simple reason that assumptions on processing and representation often go hand in hand.

3.1 The nature of mental processes and representations

Models differ considerably in the nature of the processes that are responsible for the retrieval of stored information and in the nature of their storage principles. I will illustrate this by taking models of visual word recognition as a paradigmatic example.

3.1.1 *The early models*

In this domain, two dominant verbal models of lexical access were developed around the seventies of the twentieth century, each based on a particular metaphor for information retrieval. Chronologically, the first model was John Morton's (1969) logogen model, whose basic units are so-called logogens (etymologically, the term 'logogen' is derived from the Greek words *logos* and *genus* and, hence, means something like the birth of a word). Logogens form an interface between the physical world (e.g., a printed word) and all linguistically relevant properties of the word they represent. Basically, a logogen is a recognition device that collects information about the presence of 'its' word in the outside world. Its mode of operation is based on the way a neuron works. A neuron, the basic processing unit in the neocortex of the brain, receives small electrical impulses from other neurons, which raise its state of activation. When a particular activation threshold has been reached, the neuron responds by generating an output of electrical activity itself (it is said to 'fire'), which serves as the input to other neurons. The technical properties of a logogen largely correspond to this: (i) it has an activation level, which is directly proportional to the match between the word it represents and the word that the reader is fixating and (ii) it has a recognition threshold, which is the level at which sufficient activation has been collected for the logogen to 'fire'. At that moment it has recognized the word it represents and makes all linguistically relevant information (meaning, pronunciation, etc.) available to the language processor. A logogen's threshold level of activation is a direct function of the word's frequency, such that words that are frequently used have a lower threshold, i.e., are recognized sooner, than lower-frequency words. Thus the model explains one of the most stable effects in the word recognition literature: the frequency effect (see below).

The other model is Ken Forster's (1976) search model. Whereas Morton's model takes neuronal functioning as a metaphor for lexical access, Forster's model is inspired by an entirely different sort of metaphor: that of a sequential search through a database. Forster makes the comparison with the way a book is retrieved from the correct shelf in a library.

First (at the time of the model's conception) one searches the reference to the book's physical location in a collection of index cards, each containing the bibliographical description of a book and a code referring to the book's location in the library. These cards are alphabetically ordered to make the search process as efficiently as possible. Then, one uses the reference number on the index card to physically locate the book and retrieve it from its shelf. This two-step process also occurs in Forster's search model of lexical retrieval. The model distinguishes between two types of files: access files and a master file. The former contain modality-specific representations for each word (orthographic ones for visual word recognition, phonological ones for auditory word recognition, syntactic-semantic ones for word production) and a pointer to an address in the master file. This master file contains the proper lexical representations, which store all lexically relevant information for each word (its pronunciation, spelling pattern, syntactic properties, meaning). For instance, the recognition of a written word is supposed to proceed as follows. First, the word's orthographic pattern is looked up in the orthographic access file, which is searched in a sequential fashion until a match is found. This search process is efficient because it implies an ordered search, not on the basis of alphabetical order (as in a library) but on the basis of descending frequency, such that the access codes for high-frequency words appear earlier in the search sequence than those for low-frequency words. Thus the search model accounts for the word-frequency effect as well. Once the word's access code has been found, a reference to the appropriate address in the master file also becomes available. There the processor finally retrieves all lexical properties of the word.

3.1.2 *Interactive-activation models*

The basic process behind the logogen model, activation, has survived in many later and current-day models, although the architecture of these models has become much more elaborate and has been made so explicit that they can be transformed into computational models. The activation concept lies at the heart of McClelland and Rumelhart's (1981) and Rumelhart and McClelland's (1982) interactive activation (IA) model, the first computational model for written word recognition that was explicitly designed to simulate experimental findings and, hence, to put the validity of its architectural distinctions to the empirical test.

In this model, the input of a written word starts activating information at the lowest level of representation, the representation of letter features, which pass on their activation to all representations of letters containing these features. Once a letter representation has accumulated so much activation that its threshold is exceeded, it activates all word representations containing that letter in that specific position (e.g., *t---* will activate *take, tall, task* but not *mist, step* or *rust*). Finally, at the word level, the same principle applies: each lexical representation accumulates activation that it receives from letters appearing in the appropriate word position until the recognition threshold of one representation is exceeded and the word is recognized.

Two additional remarks on activation must be made. The first concerns the nature of the effect that activation brings about. That effect can be both excitatory or inhibitory. The former notion refers to the fact that activation brings the state of the representation closer to its threshold, whereas the latter refers to the opposite: adding activation has the effect of bringing the state of the representation closer to its activation baseline. Note that these two concepts are also borrowed from neuroscience: some neurons make the neurons they project to more active, whereas others inhibit other neurons' activity level. Whereas the notion of inhibition might sound strange at first, it is easy to make intuitive sense of it: if, for instance, we were not able to disregard or ignore i.e., inhibit much of the incoming sensory data, our processing system could not make any selection between relevant and irrelevant information.

In models of the IA type, representations between levels are connected either by excitatory or inhibitory links, depending on whether the information represented at the lower level is part of the information represented at the higher level or not. For instance, an active representation of the letter *f*--- in word-initial position of four-letter words will increase the activation level in the word representations for *fake, feel, film, firm, fool,* etc. but reduce the activation level in representations for words like *soft* and *wolf* (non-initial *f*), or *cake, bear, lock,* (no *f*), etc. As far as connections between representations at the same representational level are concerned, the effect of activation is inhibitory (known as lateral inhibition). This makes intuitive sense, as one cannot simultaneously recognize two different letters in word-initial position or two different words in the same letter string. The result of lateral inhibition is that all word representations that are activated to some extent (as the result of sharing letters in the same position) will exert an inhibitory effect on each other's activation level. However, as this inhibitory effect is proportional to their own activation level, the representation that reaches the highest level of activation on the basis of the letter-to-word connections will ultimately be the only one to remain active and thus win this 'competition'.

A second property of the activation concept in IA models concerns the directionality of the activation stream, which is bi-directional. This is a defining characteristic of these models, as they have been named after it: *interactive* activation models. Hence, in IA models, activation is not only sent forward, i.e., to a representation at a later processing level, but also flows back to the representation it came from, more particularly, through a feedback connection. All bottom-up connections are matched by top-down connections between the same representations. For instance, letter representations activate word representations, which feed their activation back to the letter representations they have been activated by (inhibiting others at the same time), thus further increasing their own activity level. This interactivity between levels made it possible to explain why people recognize the same letters better in words than in nonwords or random letter sequences when the visual stimulus is barely visible (extremely short presentation, immediately overwritten by other visual stimulus), the so-called word superiority effect. At any rate, the result of the interactive activation process is that activation loops emerge in the model, which serve to quickly ‘filter out’ the lexical representation that matches the input, in cooperation with the process of lateral inhibition. Once the model has reached this stable state, the word has been recognized.

The IA architecture has been the inspiration for several specific models: in the domain of visual word recognition, both in the study of the mental lexicon of monolinguals (Grainger & Jacobs 1996) and bilinguals (Dijkstra & Van Heuven 1998, 2002), in the domain of auditory word recognition (Elman & McClelland 1984; McClelland & Elman 1986), and in the area of speech production (Dell 1986).

3.1.3 *Connectionist models*

Connectionist networks are quite similar in their mode of operation to IA models. As a matter of fact, it is the logic behind IA models that has caused the emergence of connectionism, only a few years after the two seminal papers by McClelland and Rumelhart. Moreover, the very same researchers were behind the two equally seminal books on what they called parallel distributed processing (PDP), but which undoubtedly marked the emergence of connectionism (McClelland, Rumelhart, and the PDP Research Group 1986, Rumelhart, McClelland, and the PDP Research Group 1986). Connectionism has become highly influential in current-day psycholinguistic modeling. In contrast to IA models, connectionist models have no built-in functional architecture (like letters feeding input to words). Their main strength, according to the proponents, is their ability to discover the systematicity between two types of representations, for instance orthography and phonology, and to internally represent it without the necessity to appeal to linguistic concepts and rules (see below).

The basic architecture of a connectionist model is a series of three layers, each consisting of a set of nodes: an input layer, an output layer, and a so-called hidden layer, which is situated in between the previous two. Both the input and output layers are fully connected to the hidden layer, which means that each node in these layers is connected to each node in the hidden layer. Each connection is associated with a weight determining how much of the activation that is transmitted by the sending node is actually received by the receiving node. The hidden layer is required because the systematicity in mapping representations at the input layer to representations at the output layer is generally not of the one-to-one type (if the latter were the case, a set of direct connections between two layers would suffice). The lack of one-to-one mappings is typical for language. The relationship between orthography and phonology represents a prototypical instance of one-to-many mappings (e.g., in English the letter *e* sounds differently in words like *the, bed, care, eject, hypotheses,* etc.).

The two essential processes in connectionist models are ‘activation’ and ‘backpropagation’. We are already familiar with the notion of activation. Backpropagation is a supervised learning technique that makes it possible for the connectionist system to learn the regularities that are implicit in the training pairs. Before a connectionist network can function on its own, it must first go through a training/learning phase, in which it is presented with a long list of input-output pairs, i.e., examples of correspondences. In the initial internal state of the network all connection weights between nodes are set at a random value. The input will pass through the network as a function of these weights, which will determine the representation that is formed at the output layer. As nothing has been learned yet this output will certainly be wrong. At that point the concepts of 'backpropagation' and 'supervised learning' come in. The idea is conceptually simple: for each node in the output layer a measure of divergence between the observed and the desired output is calculated (the error) and each of these errors is used to adjust the settings of the weights between layers. Technically, this is a backwards propagation of the error, which explains why the technique is called 'backpropagation'. These adjustments make it possible that the model performs slightly better the next time, i.e., that it learns. This kind of learning is supervised because there is someone who provides the model with the correct response and, hence, makes the process of backpropagation possible.

The above-mentioned process of generating very wrong to partially wrong outputs and adjusting the connection weights will continue for a long time. However, at the end of a long training session the system will be able to produce the correct output for each input it has been given in the training set. Moreover, it will be able to generalize this knowledge, i.e., to correctly apply it to instances that it has never encountered before. What has happened? What certainly has not happened is that the system has learned paired associations. Rather it has adjusted its weights for a large number of connections in such a way that, collectively, these weight settings implicitly represent the systematicity that is implicit in the input-output pairings. Nowhere in the system can one discover what the system exactly represents. There are no nodes for words or letters or whatever linguistic units. The nodes, connections, and numerical weights come linguistically unlabelled. And even though the system behaves *as if* it has discovered the rules for mapping an input onto an output, it has only induced the inherent regularities without explicitly representing rules. Illustrative examples of the connectionist paradigm are to be found in publications by Rumelhart and McClelland (1986), Seidenberg and McClelland (1989), Seidenberg and Elman (1999a) and Seidenberg, MacDonald, and Saffran (2003), although many others could be cited. The titles of the latter two papers "Networks are not hidden rules" and "Are there limits to statistical learning?" clearly reveal what the essence of the connectionist endeavour is: accounting for language behaviour on the basis of statistical learning rather than the learning of rules. Connectionist models represent the correlational structure behind input-output pairings, no rules.

In current-day psycholinguistics, IA and connectionist models are almost exclusively used to model participants' results in real-time experiments – and quite successfully I must add. However, they are quite different types of modeling. Although both originate in the idea that activation is the central concept for mapping an input onto an output, their internal architecture is radically different. IA models make use of an architecture in which the basic representational levels are identified (e.g., letter features, letters, words) revealing the hypothesis of the model's designer about the types of representations that are functionally relevant for the task. Connectionist models rely on an architecture that makes it impossible to discover this functional model in the designer's mind. As a matter of fact, the designer does not have such a functional model in mind, first of all because all knowledge is distributed throughout the model, and second because the researcher's only concern is to make a language process work without labeling what it does to what kind of representation and without taking existing linguistic concepts for granted (as these may only exist in the linguist's analytical mind).

Note that both model types can represent the same kind of knowledge (e.g., how graphemes are mapped onto phonemes). However, IA models will reveal how they accomplish this job whereas connectionist models will not. In line with this architectural difference one talks about localist representations (IA networks) and distributed representations (connectionist networks). A distributed representation is literally distributed across the set of nodes, their interconnections, and the weights in the system. Some researchers explicitly opt for an IA model because they consider it their primary goal to discover the internal structure of the language processing device that they are studying, i.e., identify its functional components and label them, rather than finding a solution that solves a mapping problem (e.g., between orthography and phonology) but in their view is uninformative at the theoretical level (a set of weights). For instance, Coltheart et al. (2001) write: "We are adherents of Old Cognitivism, and so our main interest is in the internal structure—the functional architecture—of human cognitive systems. [...] our view is that the past quarter of a century of empirical and theoretical research on reading has provided us with good reasons for proposing a particular architecture for the human reading system, and our preference is to rely on this body of literature, rather than on backpropagation, for ideas about what this architecture might be."

3.1.4 *Exemplar models*

A final class of models that has potential use for psycholinguistics but is (too) seldom appealed to for addressing psycholinguistic issues is the class of exemplar-based learning models. Several such models exist: Skousen's Analogical Model (Skousen 1989; Skousen, Lonsdale, & Parkinson 2002), Nosofsky's Generalized Context Model (Nosofsky 1988), and the TiMBL model by Daelemans and Van Den Bosch (2005). They have all been developed with the same goal in mind: the classification of a novel input on the basis of its similarity to a set of stored exemplars. Like connectionist models they set out from a 'blank slate' and must go through a training phase. Both model types differ considerably, however, in what they do with the training exemplars. Connectionist models 'forget' all individual exemplars but induce the implicit regularities and sub-regularities and encode them in the weights between nodes, thus representing patterns of systematicity in the training data. In contrast, exemplar models do not forget individual exemplars but keep track of each one of them by storing them in a memory component. Nor do they encode the regularities in the training data; rather the result of their learning process is the weight of each feature in the feature-encoded input for the purpose of classification (e.g., regular vs irregular past tense). Despite these differences, each type of model can generalize what it has learned in the training phase to novel instances. However, as their learning product radically differs, they accomplish this generalization task also in totally different ways. Connectionist models 'squeeze' the novel input through their network of weighted connections, producing an output at their output layer. Exemplar-based models use their feature weights for calculating a distance between the novel input and each stored exemplar in their memory component, determine the set of most similar exemplars, and perform the classification task on the basis of the dominant class in this nearest neighbours set. To accomplish this, they make use of a metric for determining similarity, a mechanism for determining the set of nearest neighbours, and a decision mechanism for categorizing the novel input as an instance of category A or B (e.g., "takes one type of plural or another", see Keuleers, Sandra, Daelemans, Gillis, Durieux, & Martens 2007).

3.2 Rules or no rules: That's the question

The question whether rules in language have their mental counterpart in the human mind has been a lively topic of discussion over the past couple of decades. This has been especially the case in the area of inflectional morphology, where the question arises with respect to regularly inflected verbs. Linguistically, the morphological structure of regular verbs can easily be described by (simple) rules of the type "add *-s* to stem" or "add *-ed* to stem". From an intuitive perspective it is almost self-evident that language users store such simple rules in their processing system for language. On second thought, however, one must admit that rules are descriptive tools used by grammarians, which need not correspond to what language users mentally represent. Moreover, rules are by definition abstract, and it is unclear at what level of abstraction language users represent their knowledge of a language. So, there is a real empirical question here, touching one of the essential questions about the nature of human cognition: how abstract are mental representations?

This question inspired the psychologist Steven Pinker to write his book *Words and Rules: The Ingredients of Language* (1999), in which he argues that symbolic rules are required to account for the experimental data on regular and irregular past tense formation in English. In his view, regular forms are generated by rules whereas irregular forms are represented in an associative memory component, such that subregularities within the irregular domain, like the alternation between /I/ and /a/ (*sing-sang, ring-rang, drink-drank, sink-sank* but *bring-brought, think-thought, link-linked*), can be captured. Besides grammatical rules, there may also be rules that map one type of representation onto another, such as the sublexical correspondence rules that have been proposed for transforming a grapheme sequence into a phoneme sequence. The Dual Route Cascaded model proposed by Coltheart, Rastle, Perry, Langdon, and Ziegler (2001) is a model that makes use of such rules.

However, not all models make use of rules. As has become clear in the paragraph on connectionist models, this model type can capture regularities in a set of training data and, hence, display rule-like behaviour, without actually representing rules that operate on linguistic categories (symbols). The only thing to be found inside their architecture are connection weights. There have been attempts from researchers with a rule-based view to counter the connectionist denial of rules by arguing that what is encoded in connectionist models are rules in disguise or hidden rules. For instance, according to Marcus (1999b) "Seidenberg and Elman have not gotten rid of the rule; they have simply hidden it." However, connectionist protagonists have rejected such critiques and argued that Marcus misinterprets his own experimental data: "Rather than showing that rule learning is 'there from the start' (4), the findings in Marcus et al.'s report indicate that infants are able to encode multiple types of statistical regularities." (Seidenberg & Elman 1999b, p. 433). Moreover, from the perspective of these connectionists, researchers like Marcus try to save the existence of rules in the mind by changing the definition of the word: "What has actually happened, as Marcus' comments illustrate, is that the concept of 'rule' is being altered to conform to the properties of connectionist networks." (Seidenberg & Elman 1999a, p. 288). Clearly, the question whether the language processing system actually represents rules or whether such rules are merely easy, descriptive devices that some researchers 'project' onto the human mind has been far from solved.

4. Major methodologies

The purpose of this section is not to describe all possible experimental tasks that are used in psycholinguistic experiments. First, there are so many of them that the reader would soon be bored. Second, there is little sense in describing such a task outside the context of a specific experiment. However, in an introduction to the field of psycholinguistics, it is useful to present an overview of the general methods and experimental techniques that are used in this type of research, as these are the basic instruments in the psycholinguist's toolkit. At this general level, a distinction can be made between three methodologies: corpus research, experimentation, and simulation.

4.1 Corpus research

The analysis of a corpus of language material that forms a representative sample of the phenomenon under study has been used with much success in a variety of psycholinguistic areas, particularly in areas where the measurement of the online process of language use, i.e., real-time measurement, is either unnecessary for the topic of investigation or hard to achieve. Three domains where corpus research has been especially useful are the study of children's language acquisition, the early studies of the speech production process, and the study of the spelling process.

In the study of language acquisition, researchers collect a sample of a child's language output in a particular period of development and attempt to infer its lexical and grammatical knowledge by studying the frequency and distribution of particular word types or grammatical constructions in the corpus. Negative evidence, in the form of the absence of a word or construction at a particular developmental stage or in the form of frequent errors of a particular type, can be as informative as positive evidence, i.e., the frequency and distribution of particular language elements in the corpus. (see also the chapter by Gillis and Ravid in the present volume)

The study of speech production, especially in the early period (the eighties of the previous century), has also benefited substantially from corpus studies, more particularly, analyses of large collections of speech errors. A careful and systematic study of these errors allowed researchers to identify the language elements that are treated as separate units by the speech production system and even make statements about the relative ordering of different representational stages in the production of a sentence (Fromkin 1971, 1973; Garrett 1975).

Similarly, the study of spelling errors, both the ones that occur and their distribution and the ones that could occur but do not, has enabled researchers to derive conclusions with respect to the representations and processes causing the errors. Researchers have followed the same rationale as those studying speech errors: when an error can only be explained by assuming the derailment of a particular mental process or the assumption of a particular mental representation, this can be taken as indirect evidence for the existence of this process or representation (Largy, Fayol, & Lemaire 1996; Sandra & Fayol 2003; Sandra, Frisson & Daems 1999).

Note that in each of the three domains just mentioned, techniques have been developed to study (some) processes through the use of online measures (see below).

4.2 Experimentation

This is an entirely different way to assemble data on a psycholinguistic question. The current volume contains a separate chapter on experimentation, in which two important sets of knowledge for successfully performing an experiment are discussed: the basics of experimental design and the basics of statistical significance testing. The latter part includes a clarification of the general rationale behind significance testing, which forms the foundation of any statistical test, but also describes the logic of a small number of frequently used tests in psycholinguistic research. Although a lot of attention is spent in that chapter on the technical aspects of the experimental method, there is little discussion of the actual methodologies that are used in current-day psycholinguistics.

Before turning to a brief review of these methodologies, two general remarks with respect to experimental methodology are in order. First, each experiment is an attempt to understand a particular phenomenon by making a highly controlled design for collecting data on that phenomenon. In this design, researchers manipulate one or more factors that they assume to affect a mental representation or the access speed to that representation (e.g., high-frequency vs low frequency words; words that appear in many derivations and compounds vs words that do not, etc.). At the same time, they match the words in all conditions that are compared to each other on all other factors that could affect the measurements (e.g., word length, number of words differing in one letter, i.e., so-called neighbours, etc.). Second, an important distinction must be made between so-called offline and online measures. An offline measure does not tap into an ongoing language process but only registers the outcome of that process. Hence, it is not a measurement of that process in real time, whereas an online measure is. Examples of offline measures are the number of errors made on a particular word type in an experimental task, or the ratings on a seven-point scale of the semantic relationship between two words. Examples of online measures are the time it takes to make a particular decision on a word, to fixate a word during sentence reading, to produce the name of a picture, etc. The dynamics in the output of brain imaging techniques are, obviously, also an instance of online measurement.

From my own perspective, all available online methodologies can be sorted into two general categories: chronometric studies and brain imaging, respectively tapping the participants' processing speed and brain dynamics while they engage in a language task (e.g., read a word, listen to a sentence). Note that the category of chronometric studies comprises a large variety of experimental tasks. However, here we will focus on what the experimenter measures rather than on the task that the experimental participant has to perform.

4.2.1 *Chronometric studies*

Reaction time (RT) measurement is the oldest technique that attempts to tap into the processes underlying language use. It is based on the straightforward assumption that a more complex mental processing task takes more time to finish and that an estimation of this time (the termination of a mental process is obviously not directly observable) can be obtained by having experimental participants make a response to a stimulus (e.g., a word, a sentence). When the hypothesized type of complexity is experimentally manipulated, through the presentation of complex and less complex items, and this turns out to have a significant impact on the RTs, the experimenter concludes that the manipulated variable must be part of a processing model. For instance, if one hypothesizes that the occurrence frequency of a word in written texts determines the time it takes to access its lexical representation in the mental lexicon (expecting shorter access times for high-frequency words) this should be reflected in the time that elapses between the presentation of a word and participants' overt response to it, for instance, a button press indicating their decision that the presented item is an existing word rather than a made-up pseudo-word like *blurk*. If responses are indeed faster on high-frequency words than on low-frequency words, one can conclude that frequency is a determinant of lexical access.

RT measurements bifurcate into two different methods for measuring participants' access speed to a mental representation: those including a conscious decision on the part of the participant (e.g., lexical decision: "Is the word on the screen an existing word or a pseudo-word?") and those without such a decision component, which instead rely on a behavioural index that is assumed to correlate strongly with the ongoing mental activity. A large majority of psycholinguistic experiments makes use of the first method. However, despite the huge popularity of this type of chronometric research and the fact that many data patterns obtained through its use have turned out to be replicable, it has a disadvantage. The introduction of a conscious decision process inevitably adds an extra component to the RT measurement, which causes 'noise' in the RT data. Indeed, the time that is needed to make a decision is not a constant: it varies from one participant to the other and, within an individual participant, from one item to the next. Hence, the registered RTs by no means directly reflect the effect of the design factors on the processing aspect one wants to capture (e.g., lexical access), as they do not only covary with these factors but also with this decision component. Crucially, the contribution of the latter component to the RTs cannot be removed because it is not manipulated by the experimenter but represents a source of random variability.

In addition, a decision component obviously introduces a short period between the termination of the targeted mental process and the participant's actual behavioural reponse (e.g., button press), the period within which the decision is made. During this period, extra processing of the language stimulus can continue, creating an often invisible trap for researchers: the possibility that some effects can originate during this temporal window rather than during the preceding phase of mental processing that forms the focus of the experiment. For instance, when one wants to find out whether people recognize the word *mouse* faster after just having read *cat* than after having read *pot* (to test the presence of associative relations in the mental lexicon), one should consider the possibility that participants may notice this relationship *after* having accessed the lexical representation for *mouse.* If they indeed become aware of this relation during the post-access stage, they can rely on it when making their decision (e.g., "A relationship between two items can only mean that they are both words. So, this must be a word."). Hence, the observation of faster responses in the condition with associatively related targets would in principle be ambiguous, as it could arise at two different loci in the processing course: during lexical processing and after this processing has been finished. Obviously, only the former locus is of theoretical interest and can inform researchers on the structure of the mental lexicon (in the present case, that the first word preactivates the second one through an associative connection).

Several researchers have worried from early on (already in the eighties of the previous century) that tasks including a decision component may not reliably reflect the true processes under study – for the simple reason that language users do not make conscious decisions during natural language processing – and, hence, cause a contamination of the true measurements. For that reason, they have looked for techniques that more directly tap into the mental processes under study. The registration of partipants' eye fixations during language processing has become a very popular alternative to the classical RT studies (at least, in the domain of reading, and also to some extent in the study of speech perception, see Sections 6 and 7). This technique does not involve any conscious decision; it is only used to monitor a participant's eye fixations while that participant is performing a normal language task. The description of an eye fixation pattern involves questions as: "Where do the eyes 'land'?", "How long does it take before they jump to a different place (technically: make a saccade)?", "When do they make a regression and to which position?". Eye tracking is based on the assumptions (i) that the eyes do not fixate a visual stimulus (like a written sentence) randomly but only fixate those parts that draw the person's attention because they are momentarily relevant (e.g., the word they are currently processing) and (ii) that they spend no longer on each part than necessary. Thus eye fixations are assumed to reflect quite accurately what is occupying the mind at that particular point in time and are, hence, considered to provide a clear window on mental processing. By studying how long the eyes fixate a particular type of stimulus relative to a control stimulus one can draw inferences with respect to the importance of the underlying factor for mental representation and processing.

4.2.2 *Brain imaging*

Brain imaging is a relatively new technique in the field of psycholinguistics. It has become more and more popular in the first decade of the new millennium. Several researchers attempt to pick up with this new technique and at some research centres, a lot of research on language (and other forms of cognitive and perceptual) processing is performed by making use of various brain imaging methodologies. A well-known centre is the *Donders Institute for Brain, Cognition and Behavior* in Nijmegen, which was opened in 2002 and where research on language and other forms of processing is done in close collaboration with investigators at the nearby *Max Planck Institut für Psycholinguistik* and staff members of the Radboud University.

Three often used techniques in the area of brain imaging are ERP (Event-Related Potentials), PET (Positron Emission Tomography) and fMRI (functional Magnetic Resonance Imaging). In ERP research one attempts to identify changes in the EEG signal that are time-locked to the onset of a particular type of linguistic input, which represents a condition on a variable under study. The significance of some of these time-locked changes in the signal has given rise to a relative consensus among researchers. For instance, the so-called N400 is a negative deflection (hence, the N) in the EEG graph that typically occurs 400 ms following a semantic violation (e.g., *The zebras were chased by the mice and ran away in panic*), whereas the so-called P600 is a positive deflection (hence, the P) in the EEG pattern that occurs 600 ms after several kinds of grammatical errors, like agreement errors (e.g., *The man buy a new car*), or atypical grammatical constructions, like garden path sentences (e.g., *The broker persuaded to sell the stock was tall.*).

Whereas ERP research is based on the measurement of the brain's electrophysiological activity, PET and fMRI scans are instruments that measure changes in the brain's metabolism, i.e., its rate of energy consumption. A PET scan, which can be made upon the injection of a small quantity of radioactive substance, visualizes brain regions where the neurons use more energy and, hence, where there is more blood flow to provide the necessary oxygen. Thus PET scans indicate which areas are actively involved in (one component of) the task that must be executed. An fMRI scan, which is based on a non-invasive technique (no injection), reflects the rate at which the neurons in different brain areas consume oxygen by measuring the magnetic properties of hemoglobin in the bloodstream (which change as the result of oxygen consumption). Thus the fMRI technique can be used to visualize active brain regions in response to a particular processing task, like language processing.

4.3 Simulation

Simulation does not measure language users' products (e.g., error frequencies as in corpus research) or aspects of their mental processing (e.g., response speed, changes in the brain's electrical or metabolic activity in an experiment). Rather, its purpose is to wed the tools from the field of computational linguistics to the data patterns obtained through experimentation or corpus research, in an attempt to reproduce (simulate) the human data. When trying to do so, researchers rely on a computational model of language processing that has been accurately specified in terms of the nature of its data structures (representations) and computational processes. The extent to which the model succeeds in mimicking the behavioural data determines how well the theoretical assumptions on which it is based are compatible with the nature of the mental representations and processes in real language processing. Thus a simulation is an important tool for assessing the validity of a theoretical framework for data interpretation. The implementation of this framework in the form of a computational model can lead to its rejection or serious revision.

As a computational model represents the chief aspects of that part of reality that is modeled, it should also be able to make predictions with respect to that reality, in this case, language behaviour. This is the ideal to strive for, but thus far few attempts have been made to accomplish it: build a model that cannot only account for observed effects in psycholinguistic experiments on a *post hoc* basis but can also predict effects that should be observed in an experiment if the model represents a correct theory on the object under investigation.

Thus, once again, I would compare a computational model for language to a meteorological model, whose knowledge base contains all variables and interactions between these variables that are known to affect the wheather and which continually receives updated inputs with respect to these variables from places on a network around the globe. Such a model cannot only explain the current wheather but also predict the weather that is still to come. In the same vein, adequate computational models of language should not only be able to explain the observable data patterns in past experiments but also make fairly reliable predictions with respect to observations that still have to be made with respect to a particular question. This marriage between psycholinguistics and computational linguistics is known under the name *computational psycholinguistics* (Crocker 1996; Daelemans & Van Den Bosch 2005; Dijkstra & de Smedt 1996).

5. Major research techniques

The concepts of 'methodology' and 'technique' are closely related and sometimes used interchangeably. For the sake of exposition I have opted to make a distinction between them. This distinction is, admittedly, debatable but it only serves a pragmatic purpose. It is based on the fact that empirical research on language can differ with respect to (i) *the nature of the data* that are collected (e.g., corpus data, RTs in an experiment, a simulation output) and (ii) *the specific 'trick' that is used for collecting these data.* This distinction corresponds to my use of the words 'methodology' and 'technique', respectively. The notion 'trick' may refer to a multitude of issues, as will become clear in this section: the way in which the materials are presented, the relationship between successive items, the use of a familiar effect as a benchmark for studying the effect of another factor, etc.

My description of this terminological distinction may be too abstract to be informative. To make it more concrete, I will briefly describe three categories of experimental techniques that are frequently used in the psycholinguistic study of the mental lexicon (each of these 'parent' techniques has produced several descendants over the years). Note that this is not an exhaustive list. These particular techniques enjoy a high popularity score because they have proved to be quite successful in testing hypotheses across a large variety of research topics, both in psycholinguistics and in other areas of experimental psychological research (human perception, other forms of cognition, memory, emotion,...).

5.1 Using single words to discover important representational factors

A very popular technique for investigating the mental lexicon is to mix a series of unrelated words (sometimes among pseudo-words) and present them one by one at the centre of a computer screen, where they remain until the participant has made a response. Obviously, these words have not been chosen on a random basis. Several of them represent one of the conditions on a variable that is almost impossible to detect by the participants. Examples of such variables are the frequency of a word, the frequency of the stem in a derivation, a word's age of acquisition (i.e., the estimated age at which the word was acquired), a word's so-called family size, (i.e., the number of morphologically related words in which that word appears: derivations and compounds), etc. I will demonstrate the rationale behind this technique by means of the variable that has probably been used more often than any other when studying questions relating to the mental lexicon: occurrence frequency.

Frequency is a particularly potent factor in our memory system. Our memory seems to keep track of the number of times we have experienced or done something. Situations and simple stimuli (like words) that we have often encountered are easier to recognize than comparable situations and stimuli that we have encountered less often. We all recognize a friend or family member we have often met in the past far more easily than a person we have seldom met but who is comparable in all other respects (height, weight, looks, …). Similarly, the more often we have performed a certain action, the easier we find it to perform that same action on a next occasion, as we all know from our own experience. For instance, learning to ride a bike or drive a car is, for most children and young people, a slow learning process but becomes a form of automatic behaviour once they have repeated the activity sufficiently often.

These are simple observations. How the brain accomplishes this feat – the explanation behind the observations – is an interesting issue of scientific research and dispute. However, we will not enter into this discussion here, as the very fact that frequency differences in past exposure have observable implications for current behaviour is sufficient to warrant the study of the frequency factor at the level of the mental representations involved in language processing.

The first and least exciting question is whether frequency differences in our experience with words also affect the accessibility of their memory representations. They do. Words with a high occurrence frequency (high-frequency, HF, words) are recognized faster in a lexical decision task than words with a low occurrence frequency (low-frequency, LF, words), all other things being equal (Forbach, Stanners, & Hochaus 1974; Scarborough, Cortese, & Scarborough 1977). The fact that representations in the mental lexicon, a memory store for words, are sensitive to the same factor that also affects the accessibility of other mental representations (e.g., human faces) is not really surprising, as it can be anticipated that there will be general principles at work in the cognitive system, affecting the strength of all kinds of memory traces (representations). However, our knowledge that this factor strongly correlates with a word's access speed to the mental lexicon, turns it into a powerful diagnostic when studying more complex issues of lexical access, as will become clear below.

One question in the literature on visual word recognition that has attracted a lot of research attention concerns the issue of so-called morphological decomposition: are derivations and/or compounds decomposed into their constituent morphemes before access to their lexical representation can take place? From a computational perspective, this is quite plausible, certainly in the case of derivations. Derivations with the same stem might all be accessed through the representation of this shared stem. Indeed, there are two frequency-related reasons why the letter string of a derivation could 'fall apart' into its morphemic constituents, even before the word itself is recognized. First, the frequent recurrence of the letter clusters of prefixes and suffixes in several derivations (e.g., *re-, un-, de-, -ion, -ness, -less*) and second, the recurrence of the stem in several derivations (and compounds) increase the frequency of the embedded morphemes, creating local islands of relatively high-frequency letter patterns within the word, which may make the morphemes 'jump out' of the letter string as it were.

Given the above line of reasoning and the reliability of the frequency effect in monomorphemic words, making them a trustworthy index of lexical access speed, it should come as no surprise that frequency manipulation has been used as a technique for investigating the hypothesis of prelexical morphological decomposition (Taft 1979). The logic behind Taft's experimental design was both simple and impeccable. It was also based on a clear rationale: (i) if a (prefixed) derivation is automatically morphologically decomposed, (ii) if its stem is used as the word's code to provide access to the mental lexicon (where the whole word is stored) and (iii) if frequency determines the speed of accessing such codes which is an established fact, then one can use frequency manipulation of the stem to test the prelexical decomposition hypothesis. As two types of frequencies are associated with derived words – the frequency of the derivation itself and the frequency of its constituent morphemes – Taft selected two sets of derivations that were contrasted on their stem frequency (HF vs LF stem) but matched on their whole-word frequency (they were also matched on length). The hypothesis of prelexical morphological decomposition predicts faster recognition times for derivations with a HF stem, which is what Taft found in a lexical decision task.

He observed the same phenomenon for inflected word forms: items matched on form frequency and letter length but contrasted on the summed frequency of all inflected word forms containing their stem (which he called their base frequency) were recognized faster when they contained a HF base than a LF one. Thus the technique of frequency manipulation provided evidence in favour of a process of automatic prelexical decomposition of (prefix-)derived and inflected words and, hence, suggested a model of the mental lexicon in which all stem-related affixed words are accessed through a shared stem representation.

A lot of work on the role of morphology in visual word recognition has been done since Taft's thirty-year old experiments, of course (for a review of this literature, see Diependaele, Grainger, & Sandra 2009). The point of describing Taft's experiments is to demonstrate how a familiar effect, like word frequency, can be used as a diagnostic tool for addressing a new research question.

5.2 Priming

In contrast to using isolated words, investigators have also tackled many research questions by appealing to a technique that is explicitly based on the presentation of pairs of words. The words in these pairs are related on a dimension of theoretical interest (e.g., phonological or associative relatedness). This technique is known as priming and has become highly popular over the course of the years, in many areas of experimental psychology.

In psycholinguistics, priming is a technique that is used to study the effect of one word or syntactic construction (the prime) on the recognition or production of a subsequent word or syntactic construction (the target). This effect can be either positive, in which case the prime is said to *facilitate* target recognition or production, or negative, in which case the prime is said to *inhibit* target recognition or production. Whatever the nature of the effect, when researchers observe that primes of a certain type affect the recognition or production of targets of a certain type, they take this as evidence that these prime and target types access shared or interconnected mental representations, i.e., that the theoretical dimension on which they are linked plays a role at the level of lexical organization. Note that this is a very reasonable assumption: the access to one representation can only affect the access to another if the two overlap to some extent (in the extreme case, are identical) or are somehow structurally connected in the memory system representing language. Hence, when the priming technique is used with language materials, it opens unique opportunities for studying the internal structure of the mental lexicon.

Priming is an umbrella term, as it comes in a large variety of flavours, each suited to a particular purpose. I will not attempt to describe all possible variants of the priming technique but will emphasize three dimensions with respect to which each specific priming technique can be situated. These dimensions may not be exhaustive but certainly cover a broad range of applications of the technique in the literature.

The first dimension is the *relationship between prime and target.* The nature of this relationship is, of course, the main reason why the technique is used at all. As already mentioned, when a particular prime-target relationship causes priming effects, the underlying rationale of the technique supports the conclusion that this relationship is somehow encoded in the structure of lexical representations, their connectivity patterns, or the nature of the access mechanism. For instance, if one wants to find out whether the process of word recognition is affected by phonological factors, i.e., whether lexical access is sensitive to phonologically similar words in the mental lexicon, one can use phonological priming. If responses to targets in prime-target pairs like *mat-cat* are faster or slower than to the same targets in matched control pairs lacking a phonological relationship, like *pin-cat,* this can be treated as evidence that the lexical access process is sensitive to phonological similarity.

Psycholinguists are interested in linguistically relevant relationships, like phonological, morphological and semantic ones, but also focus on relationships that are of little linguistic relevance, like the orthographic similarity or the associative relationship between words. Note that associatively related words need not be semantically related, although both relationships tend to co-occur (e.g., *bread-butter*). Words like *monkey* and *banana* are not semantically related – one refers to an animal, the other one to a piece of fruit – but have a strong associative relationship: the word *monkey* makes many people immediately think of the word *banana,* given the frequent co-occurrence of monkeys and bananas in reality. The fact that psycholinguists study both linguistic and non-linguistic relationships demonstrates that they approach language from an entirely different perspective than theoretical linguists. Their main focus is neither on the structural dimensions of language nor on the psychological reality of linguistic distinctions. Rather their goal is to uncover the internal structure of the language processing system, i.e., to describe the nature of the mental representations and processes that make language use possible. For instance, in the study of the mental lexicon, the ultimate purpose is to find out which dimensions determine the connectivity patterns among words and, hence, have an impact on lexical processing. Some of these dimensions may be linguistic in nature, others not at all. As mentioned in the first section of this chapter, current-day psycholinguists no longer pay lip-service to linguists by verifying their theories. Rather, they have a well-defined goal of their own (see also Chapter 1 of this volume).

A second dimension along which priming techniques considerably differ is *the visibility of the prime*. The first series of priming studies made use of a long-distance priming paradigm, in which prime and target words were both clearly visible and were separated by a number of intervening experimental trials (e.g., 48 trials in Fowler, Napps, & Feldman 1985) sometimes even by two days (Scarborough, Cortese, & Scarborough 1977). Using this technique, one discovered, for instance, that identical word repetition always leads to faster responses on the second presentation of a word but that this facilitation is larger for LF words than for HF ones (Forster & Davis 1984). One also discovered morphological priming effects from derived word primes on their stem targets (*appearance-appear,* see Stanners, Neiser, Hernon, & Hall 1979).

However, one soon hit upon an annoying possibility: the data of this type of priming paradigm were likely to be seriously contaminated by the contribution of so-called episodic memory factors (Jacoby 1983; Whittlesea & Dorken 1993). Episodic memory is a memory 'compartment' where we supposedly store all our personal experiences, for instance, what we ate this morning but also the fact of having seen the word *appearance* a few sentences ago. The contribution of episodic memory in long-distance priming is, for instance, suggested by the observation that the divergence in repetition effects for HF and LF words in a lexical decision task is parallelled by a similar asymmetry in a recognition memory test ("Did this word occur in the list you have just seen?"), where participants have to rely on episodic memory. When participants have to indicate whether they recognize a word as an instance from the study list, they perform better on LF words like *echo* than on HF ones like *man*. This suggests that LF words leave stronger traces in episodic memory than HF ones, which might indicate that LF words require larger processing demands for memory encoding (Rachel & Reder 2006). If repetition priming effects are mediated by episodic memory traces, the observed priming asymmetry for LF and HF words would be readily explained (but see Kinoshita 1995 for an argument against a common origin of frequency effects in recognition memory and repetition priming).

However, the most compelling reason for questioning the validity of these priming data for the study of the mental lexicon was a theoretical one. If priming effects can last for several minutes and even days, the consequence would be that the activation decrease in a lexical representation following word recognition occurs at a very slow rate. As a result, within a short period of time each lexical representation would be in such a high state of activation that recognition could occur on the basis of very little stimulus information. This, in turn, would annihilate the frequency effect, a prediction that is squarely at odds with the observation that this is one of the most stable effects in the literature. At this point, the technique of masked priming came to the rescue.

The masked priming technique was first introduced into the field by Humphreys and colleagues (Evett & Humphreys 1981, see also Humphreys, Besner, & Quinlan 1988; Humphreys, Evett, Quinlan, & Besner 1987) but became a very popular technique ever since the seminal work by Forster and Davis (1984). The technique owes its name to the use of a stimulus, the mask, that makes is impossible for participants to discover the identity of the prime, like a true mask conceals the identity of the person who is wearing it. Technically, this is accomplished in the Forster and Davis paradigm by presenting a sequence of three visual events: a series of hash marks (#####), which is presented for 500 ms, immediately followed by a very short presentation of the prime in lowercase letters (60 ms or less), which is in turn immediately followed by a target in uppercase letters. The target remains on the screen until the participant's response. The combined action of the temporal relationships between the stimuli and their superposition causes the impression that there are only two 'events' on the screen: a series of hash marks, followed by an uppercase letter string. Participants are surprised to hear after the experiment that on each trial a stimulus in lowercase letters had been 'sandwiched' between the hash marks and the target.

Despite the invisibility of the primes at a conscious level, many studies on different topics have demonstrated reliable and replicable effects with this technique. Most importantly for the present discussion, Forster and Davis demonstrated that the subliminal, i.e., masked, presentation of a prime eliminates the episodic effects that plague the priming paradigm with visible primes. When using a set of LF and HF words they found the typical interaction between identical repetition and frequency when the primes were visible – a larger facilitation effect for the LF words – but not when the primes were masked. In the latter case LF and HF words caused equally large repetition effects. Importantly, these could not be explained as the result of orthographic priming. Indeed, neither pseudo-word repetition *(#####-flurp-FLURP*) nor one-letter-different prime words *(#####-race-FACE*) caused reliable priming, which should have been the case if the nature of the effect were orthographic instead of lexical.

A third dimension that can be used to classify priming paradigms is the *language modality of prime and target.* Researchers who are interested in visual word recognition will obviously present their targets visually but have the choice to present their primes either visually or auditorily. The same choice situation occurs in research on speech perception, where auditory targets are used. When prime and target belong to different modalities (visual vs auditory), the technique is called cross-modal priming. Cross-modal priming has been used in a number of studies (e.g., Diependaele, Sandra, & Grainger 2005; Grainger, Diependaele, Spinelli, Ferrand, & Farioli 2003; Marslen-Wilson, Tyler, Waksler, & Older 1994; Zwitserslood 1989; see Tabossi 1996 for a relatively old review on cross-modal semantic priming) but the technique is certainly not as wide-spread as intra-modal priming. The main reason for this is probably technical: it is more time-consuming to prepare an experiment where different modalities are combined.

The logic behind cross-modal priming is quite sensible. It rests on the idea that priming effects obtained through the use of primes and targets in different modalities occur at the level of the abstract, modality-independent representation of a word. This representation bundles all specific representations of the word (e.g., orthographic, phonological), all of which are accessed through modality-specific access processes. For instance, the orthographic representation is accessed through a processing path that starts with a visual encoding of the stimulus, whereas the phonological representation is accessed through a processing route that starts with an auditory encoding. Cross-modal priming prevents the danger that the obtained effects only highlight the internal structure of the modality-specific representation (e.g., the orthographic one) rather than the structure of the abstract, modality-independent lexical representation.

5.3 Inducing interference

The attempt to create an interference effect in the processing chain deserves special mention, even though this technique is always combined with one of the two techniques mentioned above (single word presentation or priming). In contrast to the previous techniques, it is not based on the assumption that an important representational variable will leave its fingerprint on the RTs and errors or that a relationship that is encoded in the connectivity structure of the mental lexicon will affect these measures. Rather it sets out from the assumption that a processing conflict will arise when two independent processes access conflicting types of information, and that this will be detrimental for performing the experimental task: slower RTs and more errors will be observed compared to a control condition. Thus, inducing response interference can be informative on the processes that a particular simulus type sets in motion and on the nature of the representations that are activated by these processes.

One of the best-known examples of an interference effect in language processing is probably the well-known effect of Stroop interference (Stroop 1935). The experiment demonstrating the effect is a very elegant one, i.e., it does not depend on a complex design, and the basic observation can be made by anyone on a home computer or even by printing the coloured stimuli on a piece of paper. The observation is that people find it quite hard to name the colour in which a particular colour name is printed when there is a mismatch between the to-be-named colour and the colour to which the name refers. For instance, people need more time and/or make more errors when they have to say "red" when the word *green* is printed in red letters than when a word like *chair* is printed in red letters. This observation demonstrates very convincingly that experienced readers cannot ignore words, i.e., that the process of word recognition is highly automatic and beyond readers' control. They cannot decide not to recognize a word once their eyes fixate on it, even in conditions where this ability would considerably simplify their task (e.g., the Stroop test).

A second illustration of a type of experiment that capitalizes on the concept of interference can be found in research on the bilingual mental lexicon (see the chapter by Dijkstra in this volume). One of the major questions in this research domain is whether bilinguals access their mental lexicon in a language-nonselective or a language-selective way. Are they able to suppress all lexical representations in a language that is irrelevant in the current context of language use? Cognates and interlingual homographs have been ideal word types for the study of this question in the domain of visual word recognition. Both these word types have the same orthographic form in a bilingual's two languages (say English and Dutch). Cognates also share their meaning (*film*), whereas interlingual homographs do not (*room*, which refers to cream in Dutch). If the language-nonselective view on lexical access is correct, interlingual homographs should cause a temporary conflict within the reader's processing system, at least when the task is to decide whether the stimulus is, for instance, an English word. Being confronted with a matching lexical representation in Dutch and English for a word like *room,* the ensuing response confict will require the suppression of the task-irrelevant representation, which will result in longer RTs and/or an increased error rate.

A final illustration of the use of the interference concept comes from the domain of language production. A well-known paradigm in that area is the so-called picture-name interference technique, which has become popular since the study by Schriefers, Meyer, & Levelt (1990). Participants are shown a picture and are asked to name it as quickly as possible. However, on the picture itself a word is printed (at fixation position). For instance, a stimulus in this type of experiment could be the picture of a horse with the name *mule* written over it. Participants are told to ignore this word when naming the picture, as it is entirely irrelevant for their task. Obviously, the word has a well-defined function and, as researchers have learned from the Stroop effect, cannot be ignored. This makes it possible to choose words with respect to a particular variable on which the picture name and the printed word are related (semantically, phonologically, …) with the purpose of finding out whether this variable plays a role in the process of language production, and, if so, at what moment in the time course. The latter can be discovered by varying the onset of the picture and the word relative to each other (the word can also be presented auditorily).

For instance, when participants have to say "horse" but read the word *mule* at the same time, they may be confused by the semantic relationship between these two words, which will be reflected in slower naming times and/or more errors, compared to a control condition in which, for instance, the word *road* is written on the picture. By varying the time interval between the moments of picture and word onset and studying how this temporal relationship affects the absence, presence, and size of the interference effect, one can infer when semantic information is retrieved during the time-course of the speech production process (or, phonological information, when the distractor word is phonologically related to the picture name, e.g., the picture of a dog with the word *doll* printed on it). For a discussion of findings obtained with this technique, see Levelt, Roelofs, & Meyer (1999).

6. Studies on language perception

In this section I will review some of the most important insights into the perception of language, both with respect to the reading process (6.1) and to the process of speech perception (6.2). Note that this will be a highly restricted overview of the literature, as a separate chapter (or book!) could be devoted to the research that has been done on each of the four language skills. For instance, I will restrict myself to research on lexical processing and not deal with the literature on syntactic parsing during sentence comprehension, even though many studies have dealt with this issue (and others) as well.

6.1 The process of visual word recognition

A lot of psycholinguists have been concerned with the process of visual word recognition. Obviously, the recognition of a written word is only a small step in the entire set of processes that are mobilized in the course of reading a text. However, it is an important step, representing a core skill on which all other processes involved in reading a text are contingent: the retrieval of the word's meaning, the integration of that meaning into the preceding sentence fragment, which, in turn, is required to integrate that sentence meaning into the semantic representation of the whole text. As a result, people with severe problems in written word recognition usually have problems with text comprehension as well (Berninger, Abbott, Vermeulen, & Fulton 2006).

In what follows I will make a distinction between factors that are operational in the time window before a lexical representation is accessed and ultimately lead to such access, and factors that determine the accessibility of the lexical representation itself, i.e., factors that make lexical access easy or difficult.

6.1.1 *Processes at the prelexical processing level*

6.1.1.1 *Prelexical morphological decomposition*

In Section 5.1 we have already addressed the question whether morphologically complex words (inflected word forms, derived and compound words) are prelexically decomposed into their constituent morphemes, in other words, even before the lexical representation of the whole word is accessed. We will return to this issue here, because it is one of the most discussed prelexical processes in the literature. Needless to say, the hypothesized processes at this level operate automatically and fall beyond any form of conscious control on the part of the language user. Language users are also completely unaware of their existence.

Recent research seems to converge on the conclusion that morphologically complex words are automatically decomposed into their constituent morphemes at the prelexical level. This was already the conclusion of Taft and Forster's pioneering research (1975, 1976). In their 1975 paper, these authors demonstrated, for instance, that the rejection of a pseudo-word takes longer and gives rise to more errors when it occurs as a bound stem in a prefixed derivation (e.g., *juvenate* in *rejuvenate*) than when it is a matched control derived from a pseudo-prefixed word (e.g., *pertoire* in *repertoire*). This suggested to them that even bound stem morphemes have a special representational status in the mental lexicon. In their 1976 paper, they showed that the frequency of the first constituent of a compound word determines participants' response speed in a lexical-decision task, suggesting that the whole compound is accessed on the basis of its first constituent, which requires prelexical decomposition.

Although the question regarding prelexical morphological decomposition has been a dominant research theme ever since, it has seen a strong revival in the past ten years, when researchers decided to tackle the question by using the masked priming technique. Two studies in the early ages of the new millenium suggested quite convincingly that there is a stage preceding lexical access in which the processor attempts to identify letter strings that match the orthographic pattern of morphemes. Using 43 ms masked morphologically complex primes and stem targets, Rastle, Davis, Marslen-Wilson, and Tyler (2000) obtained morphological priming effects that were independent of whether the prime was semantically transparent (*departure*-DEPART) or not (*apartment*-APART). This suggests that in the very early stages of visual processing potential morphemes are identified on the basis of orthographic patterns in the stimulus word. Note, incidentally, that a prelexical process has no way of 'knowing' what the linguistic status of an orthographic segment is – it has not reached the lexical level yet – and can, hence, only be driven by pure form information.

In 2003 Longtin, Segui, and Hallé reported strong evidence in favour of blind prelexical decomposition of a word's 'surface morphology'. Using 46 ms masked morphologically complex primes and stem targets, they found significant facilitation effects on targets following semantically transparent primes (*gaufrette*-GAUFRE) or semantically opaque primes (*vignette*-VIGNE), effects which did not differ from each other, but also on targets following pseudo-derived primes, consisting of a pseudo-stem and a pseudo-suffix (*baguette*-BAGUE). The evidence that the source of this effect was the surface morphological structure of the prime, i.e., the fact that the word was a concatenation of potential morphemes based on the segments' orthographic pattern, came from a control condition. In this condition items consisted of a potential stem, followed by a letter sequence that did not match the orthography of a suffix (absence of a surface morphological structure, e.g., *abricot*-ABRI). An inhibition effect was found, indicating that only words that could be exhaustively parsed into potential morphemes (as is obviously the case for any true derivation) are decomposed.

In a recent masked priming study McCormick, Brysbaert, & Rastle (2009) wondered whether prelexical decomposition was limited to LF words or applied across the board. They observed evidence favouring prelexical morphological decomposition, both for HF and LF words, which made them conclude that the process is mandatory and indiscriminately applies to all incoming letter strings.

The discussion on whether the initial processing stages are really insensitive to semantic influences is still ongoing, as evidence has been presented, both for prefixed and suffixed derivations, both in experiments with French and Dutch words, that there is an effect of semantic transparency at very short prime durations (Diependaele, Sandra, & Grainger 2005; Diependaele, Sandra, & Grainger in press, Feldman & Basnight-Brown 2008).

6.1.1.2 *Prelexical phonological recoding*

A second candidate for a prelexical process has attracted the attention of many researchers as well: the possibility of automatic prelexical phonological recoding, i.e., the mapping of the orthographic representation of the written word onto its phonological representation. Does this process take place automatically during prelexical processing, such that lexical access can (or must?) take place on the basis of a phonological representation? The findings obtained with several variants of the masking paradigm have led to a relatively strong consensus that automatic phonological recoding is indeed an automatic prelexical process. Note that in all experiments homophonic pseudo-words (i.e., a nonword that is homophonic with a word) were used, rather than homophonic words. If words were used, the effect could equally well originate within the lexicon as prior to lexical access, i.e., the outcome would be ambiguous.

The first paradigm, backward masking, comes in different versions. Perfetti and Bell (1991) used the following technique. First they presented a word in lowercase letters (*blue*) for 35 ms, followed by a nonword in uppercase letters for 30 ms, which was finally followed by a row of *X* signs (XXXXXXXX). The participant's task was to identify the lowercase word. They found that this was easier when the uppercase nonword, which acted as a backward mask for the word, was a pseudo-homophone of that word than when it was a matched non-homophonic nonword (*BLOO* vs *BLOS*). This outcome suggested that the word had been phonologically recoded very rapidly and that this phonological representation was not destroyed by a subsequent homophonic nonword mask. In a different version of their backward masking paradigm Perfetti and coworkers (Perfetti, Bell, & Delaney 1988) again obtained a pseudo-homophone effect. This time they only superimposed the briefly presented (20–50 ms) lowercase word by an uppercase nonword.

The second paradigm is the masked priming paradigm described earlier, in which a 500 ms row of hash marks (forward mask) is followed by a brief lowercase prime word, which is in turn overwritten by an uppercase target (acting as a backward mask). Using this technique with French items Grainger and Ferrand (1996) obtained evidence for fast phonological recoding: briefly presented masked primes caused faster responses when they were pseudo-homophones of the target (*#####-lont-LONG*) than non-homophonic controls sharing the same number of letters with the target (*#####-tabe-LONG*).

Finally, Brysbaert and coworkers combined the two paradigms. In their technique the nonword did not follow the word as a backward mask (as in Perfetti and Bell's experiment), but preceded it as a prime. Hence, participants would see trials of the type *bloo-BLUE-XXXXXXX*, where both prime and target were presented very briefly (43 vs 29 ms, respectively), and would be asked to identify the target. Using this technique Brysbaert and colleagues reported two studies in which they showed pseudo-homophone priming effects. Moreover, in these studies, they demonstrated that these effects also occur across languages: an L2 word is more rapidly recognized when its prime is homophonic to it according to grapheme-phoneme correspondences in the participants' L1 (e.g., *soer-SOURD* is an example of their Dutch-French pairs of L1 pseudo-homophones and L2 targets) and, even more surprisingly, an L1 word is recognized more rapidly following a pseudo-homophone in L2 (Brysbaert, Van Dyck, & Van de Poel 1999; Van Wijnendaele, & Brysbaert 2002). Thus these authors demonstrated mandatory prelexical phonological recoding in both the first and the second language.

In a recent review of the literature Rastle and Brysbaert (2006) perform a meta-analysis on a set of published experiments, report new experiments, and simulate their results. They arrive at the conclusion that the prelexical effect of phonological recoding is small but reliable and supports the existence of a process of prelexical phonological recoding.

6.1.2 *Factors determining the accessibility of a lexical representation*

The accessibility of a lexical representation is determined by two sets of factors: those that determine the strength of its memory trace and those that affect the ultimate selection of the target representation.

6.1.2.1 *Factors affecting the strength of a lexical representation*

The strength of a lexical representation is determined by at least two factors: word frequency and age of acquisition. As the effect of word frequency has already been discussed earlier, I will only consider the age-of-acquisition effect here, although its relationship to the frequency factor has given rise to a lot of debate (see below).

The term 'age of acquisition' refers to the (estimated) age at which the word was acquired. Obviously, this factor is highly correlated with word frequency: a word that is acquired early in life often becomes a HF word (but not always; e.g., children acquire the word *fairy* early in life but in adult language use, this is a LF word). This correlation can, of course, be measured by estimating the word's age of acquisition (e.g., by asking schoolteachers at what age a word should be known) and counting the number of times that this word appears in a representative corpus of texts that adults are confronted with (for instance, the CELEX database for Dutch, which is derived from a corpus counting 42 million word tokens, Baayen, Piepenbrock, & Van Rijn 1993). The strong correlation between these two measures makes it almost inevitable that two word sets that are contrasted on frequency will also differ on their mean age of acquisition. Hence, what is the causal factor behind faster responses on HF words: their frequency or their age of acquisition?

Morrison and Ellis (1995) wrote a seminal paper in which they systematically disentangled these two factors. When contrasting two sets of words on frequency and matching them on age of acquisition they found no differences in response speed and errors in a naming task. In contrast, when contrasting two word sets on age of acquisition while matching them on frequency, they obtained reliably faster response times for the words that had been acquired early in life. This caused them to make the bold claim that all frequency effects in the literature were actually effects of age of acquisition.

However, several researchers made the counter-argument that was waiting in the wings: early acquired words are recognized faster for the simple reason that, in the course of someone's life, they have been so frequently encountered that their lexical representations have become much stronger than the representations for words acquired later in life. This account was the exact opposite of Morrison and Ellis' claim: the truly important factor is frequency, not the word frequency that can be found in a frequency count (which only estimates the frequency of a word in a selection of texts at a particular moment in time) but the *cumulative frequency* across a person's life span. Given the theoretical importance of this debate – are there two distinct factors that separately determine the accessibility of a word's representation or only a single one? – a lot of researchers set out to test the validity of the intuitively plausible cumulative frequency account.

The outcome of many experiments by even more researchers is that cumulative frequency cannot explain the observed effects. Ghyselinck, Lewis, and Brysbaert (2004) compared the effect of cumulative frequency and age-of-acquisition in a number of different tasks (naming, lexical decision, …) and arrived at two important observations and conclusions. One observation directly addressed the cumulative frequency hypothesis: in order to predict the observed RTs with a mathematical formula, the weight of the age-of-acquisition factor had to be much stronger in the equation than the weight of the frequency factor. This rejects the hypothesis that age-of-acquisition effects can be reduced to frequency effects. The second observation was that, in the majority of tasks, independent effects of frequency and age of acquisition were observed. These effects did not interact with each other but were at the same time highly correlated: a large/small frequency effect was accompanied by a large/small effect of age of acquisition. This finding suggests that we are dealing with two separate factors that are, however, both tied to the same processing stage and affect the same learning mechanism. Accordingly, the authors claimed that the evidence strongly suggests "that AoA [Age of Acquisition] and frequency effects are *both* likely to be the result of the way in which information is stored and accessed in the brain", [...] "making it difficult to maintain that they do not have a *common basis*." (Ghyselinck et al. 2003, pp. 50 and 62, respectively, my emphasis). As far as the nature of this common basis is concerned, the idea is that early words and concepts are easy to store in an (almost) empty mental lexicon, whereas the task of maintaining an integrated memory structure by adding new words becomes ever more difficult as the lexicon expands, i.e., early acquired words are more strongly anchored in the mental lexicon.

The cumulative frequency hypothesis has also been rejected by other research teams, two of which will be mentioned here. Stadthagen-Gonzalez, Bowers, and Damian (2004) used expert vocabularies to investigate the issue. They selected high-frequency words from scientific journals in the disciplines of psychology, chemistry, and geology and found that late-acquired words like *cognition* were responded to faster by experts (for whom these are HF words) than non-experts (for whom these are LF words), a pure frequency effect. More importantly, they also found two pieces of evidence ruling out the hypothesis of cumulative frequency and supporting a distinct effect of age-of-acquisition instead: (i) Late acquired HF words, i.e., specialist words, were not recognized faster than early acquired LF words like *dragon,* despite the fact that the late acquired HF words had a much higher cumulative frequency, (ii) early acquired HF words were recognized faster than late acquired HF words, despite being matched on their cumulative frequency. They concluded that "both Early and HighF words may have 'stronger' lexical representations that are more easily accessed" (p. B19). In other words, the suggestion is that both frequency and age-of-acquisition are independent factors, each of which determines the accessibility of a word's lexical representation.

De Deyne and Storms (2007) studied the phenomenon by using words that only recently entered the language, i.e., words like *mango.* Their reasoning was that an age-of-acquisition effect should be found when comparing two age groups: young adults (18–23) and older adults (52–56). The only difference between these groups is the age at which they acquired these new words. For both groups the words were matched on frequency and cumulative frequency, as there is no reason to suspect why one group would encounter these words more often than the other (still, precautions were taken to control for this risk). The outcome of the experiments were clear: the difference in word recognition times in a lexical decision task were predicted by the difference in age-of-acquisition (for each word the average age-of-acquisition in the young group was subtracted from the average age-of-acquisition in the older group) but not by the difference in the participants' rated familiarity with the words. This supports the claim that age-of-acquisition is the crucial factor, not (subjective) frequency. In separate analyses on the data of the younger and older groups, RTs were predicted both by the participants' age-of-acquisition, their rated familiarity, and the words' frequencies in a frequency count. The effect of frequency was found after the effects of age-of-acquisition and the effect of familiarity had been statistically removed. The latter finding corroborates the claim made by Ghyselinck et al. (2004) that age-of-acquisition and frequency are two independent factors that determine the accessibility of a lexical representation.

6.1.2.2 *Factors affecting the selection of a lexical representation*

I will discuss two factors that affect the ease with which a lexical representation gets selected from the large set of representations that is stored in the mental lexicon: orthographic neighbours and family size. Generally speaking, the purpose of word recognition is to select one word from a vast word pool in long-term memory. In a recognition system where only one representation gets activated by the incoming stimulus, this would be a relatively simple process. The sensory stimulus would be recoded into the format that is used by the representational system used in the mental lexicon and then directly mapped onto the appropriate representation. However, research has shown that this is not the way our word recognition system operates.

Orthographic neighbourhoods

One property of visual word recognition is that the activation of lexical representations does not follow an "all-or-none" principle, such that a particular lexical representation is either activated or not, but rather operates on the basis of similarity. The degree of similarity between a word that is being read and the orthographic pattern of a word that is stored in the mental lexicon determines the degree of activation of the latter word's lexical representation. Although similarity is a concept that is quite hard to define, a simple and straightforward operationalization for the practical purpose of item selection has been functioning pretty well for several decades already. In this operationalization a word is considered to be sufficiently similar to the input for being coactivated during word recognition when (i) it shares all letters but one with the target word and (ii) all of its shared letters occupy the same position in the word. Such a word is called an orthographic neighbour and can be obtained by replacing one letter in the presented word by another letter if that operation turns the target word into another word. For instance, given the target word *book,* some of its orthographic neighbours are *cook, hook, look, took, bonk, boom, boot*. Some words have many such neighbours, like *book,* whereas others have very few or none, like *echo.* The concept was introduced by Max Coltheart a long time ago (Coltheart, Davelaar, Jonasson, & Besner 1977) and, as mentioned, its validity has been demonstrated in many experiments, such that it is widely accepted in the field. As orthographic similarity between word forms might affect the speed of lexical processing (for the simple reason that similarity would cause the processing system to remain uncertain about the identity of the target), a lot of attention has been devoted to effects of a word's orthographic neighbourhood.

An important distinction should be made between two concepts that are associated with the notion of orthographic neighbours: *neighbourhood size,* which refers to the number of neighbours of a word, and *neighbourhood frequency,* which refers to the frequency of the neighbours (with a focus on whether the neigbours' occurrence frequency is higher or lower than that of the word that must be recognized). Hence, there are two critical questions. Does the presence of more orthographic neighbours facilitate word recognition or not? Does it matter whether one or several of these neighbours have a higher occurrence frequency than the target or not?

When studying the effects of orthographic neighbours one should be careful to methodologically separate the effects of neighbourhood size and frequency. Comparing two word sets that simultaneously differ with respect to their number of neighbours and the frequency of these neighbours would obviously make it impossible to make claims with respect to either factor. Hence, researchers should contrast one factor while keeping the other constant. Space limitations make it impossible to do justice to the large literature on the effect of orthographic neighbours but in what follows I will try to sketch the outlines of the emerging picture. (for a review up to the end of the nineties, see Perea & Rosa, 2000)

Neighbourhood size It has been found that neighbourhood size affects the speed with which a word is recognized but that the direction of the effect depends on the requirement made by the experimental task. Tasks in which the exact identification of a word is called for tend to reveal an inhibitory effect for words with high-density orthographic neigbourhoods, whereas tasks that make it possible to respond without identifying the word precisely tend to reflect a facilitatory effect when the word has many orthographic neighbours. For instance, the lexical decision task makes it possible to respond on the basis of a general index of 'wordlikeness': when a letter string looks like a word, i.e., is similar to many orthographic patterns in the mental lexicon, participants can respond 'yes' before having fully identified the word. In such a task, the presence of many orthographically similar words will cause a lot of activation in the mental lexicon (Grainger & Jacobs 1996), which participants can use as evidence that the target is likely to be a word. This is in line with a study by Andrews (1992), who found that low-frequency words are recognized faster in a lexical-decision task when they have a large orthographic neighourhood. It also fits in with the study reported by Pollatsek, Perea & Binder (1999), who equated the words in two sets on the frequency of their highest frequency orthographic neighbour while manipulating the words' neighbourhood size. In a lexical decision task, faster responses were given to words with the higher number of neighbours.

Whereas lexical decisions can be made on the basis of a sense of familiarity or 'wordlikeness', some response types cannot rely on such information because they require the unique identification of a word. Progressive demasking is an example in case. The participants' task in such an experiment is to identify the word that is on the screen. However, this is made difficult by showing the word only very briefly and immediately replacing it with a mask. The total duration of word and mask is a constant but on each cycle the word is presented for a somewhat longer duration (say, 10 ms) and the mask is correspondingly presented for a shorter duration. The phenomenological experience is that the initially hidden word is gradually unmasked (hence the name 'progressive demasking'). This procedure continues until the participant says or writes down the word that she/he thinks to have seen. In such circumstances, where precise identification matters, a large number of neighbours delays responses relative to a matched word with fewer neighbours (Carreiras, Perea & Grainger 1997). According to activation-based theories of the mental lexicon, the more neighours that are activated, the stronger the competition among these neighbours (lateral inhibition) in the selection process of word identification, which complicates the process of unique identification and, hence, causes longer response times.

Another way to avoid that participants in reading experiments rely on cues that have a large degree of response validity in the experimental context (like orthographic similarity as an index of worklikeness) is to use a method in which participants must recognize words without making decisions on them. That can be achieved by presenting the critical words in sentences that have to be read for meaning and measuring the time that participants spend on reading the critical words, using the technique of eye monitoring. Studies in which participants have to read sentences for meaning (they have to reply to a question following some sentences) while their eye movements are being monitored seem to indicate exactly the opposite effect of neighbourhood density than a lexical decision task: more orthographic neighbours increase the duration of eye fixations and cause more regressions to the word, i.e., refixations after already having moved to the next word, because readers are apparently unsure whether they have recognized it correctly.

Again the study by Pollatsek, Perea, and Binder (1999) is important in this respect. When equating two sets of words on their highest-frequency neighbour while contrasting them on their neighbourhood size, they found that words with large neighbourhoods caused inhibition effects, i.e., longer reading times during eye tracking. In another experiment they equated the number of higher-frequency words in two word sets and manipulated the neighbourhood size between these sets. Words with more orthographic neighbours were skipped more often but this gave rise to later inhibition in the reading process (slower reading), suggesting that readers had been misled by the orthographic similarity of the cricital word to many other words and selected the wrong word. In other words, the same index of familiarity, reflecting the presence of many orthographic neighbours, which is helpful in the lexical decision task, seems to cause problems in a natural reading task, which does not involve a decision component. This makes sense: a high degree of orthographic similarity with other words encourages a 'yes' response in the decision phase of a lexical decision task ("it is *a* word") but seriously complicates the process of word selection that is required in normal reading ("it is *that* word").

However, we should probably not be blinded by the task differences discussed above but by the *commonality* across tasks. The evidence indeed converges on the observation that neighbourhood size affects reading times and is, for that reason, a critical factor in the word recognition process. The observation that the direction of the effect is task-dependent is interesting, but tells us more about the processes that are mobilized by the task than about the importance of neighbourhood size for the process of word recognition.

Neighbourhood frequency What is the impact of the orthographic neighbours' frequency? The first to study this issue were Segui and Grainger (1990), using the masked priming paradigm discussed earlier (Forster & Davis 1984). They found that 60 ms primes that were higher-frequency neighbours of a LF target delayed lexical decision responses on that target whereas primes that were lower-frequency neighbours did not have an effect relative to a matched control word. This finding can easily be explained within an activation account of the mental lexicon, in which similar words are activated and compete for selection, which occurs when one candidate exceeds the activation threshold that is required for word recognition. A higher-frequency prime that is an orthographic neighbour of the target is easily activated and hence suppresses the process of activation build-up in the target's lexical representation, causing a delay in response times. A lower-frequency neighbour, on the other hand, cannot suppress the accumulation of activation in a higher-frequency target, which reflects itself in the absence of an effect.

Perea and Pollatsek (1998) came to the same conclusion as Segui and Grainger (1990), but used a different rationale and different experimental paradigms. They compared two word sets that were matched on all relevant factors but different in one respect: members from the first set had no higher-frequency neighbours whereas members from the second set had at least one such higher-frequency neighbour. They found that (unprimed) lexical decisions took longer for words of the latter set. Moreover, in an eye tracking study they found more regressions for this same set of words, suggesting that participants were unsure about the identity of the word they had just read.

However, in two recent studies Stephen Lupker and colleagues have cast some doubt on the almost axiomatic idea that higher-frequency neighbours always delay the reading process and that, when experimental techniques produce a delay, these neighbours are the only ones to cause it. Sears, Sharp and Lupker (2006) used a lexical decision task to find out whether words with higher-frequency orthographic neighbours are indeed more difficult to recognize in a simple lexical decision task and came to the conclusion that "higher frequency neighbors have little, if any, effect on the identification of English words". In a very recent publication Nakayama, Sears and Lupker (2008) used the same masking technique as in the study by Segui and Grainger (1990) but manipulated both the frequency and the neighbourhood size of both the primes and the targets. They found the same effects as Segui and Grainger but with an important qualification: orthographic neighbours of the target that are more frequent than the target itself delay its recognition, but only when primes and targets have few neighbours. When they have many neighbours, lower-frequency primes were found to delay the recognition of higher-frequency targets as well. This study not only suggests that both the frequency and the density of the orthographic neighbours are important in word recognition (that is the conclusion when looking at the entire set of studies discussed above) but that they interact with each other in unexpected ways.

Family size

The effect of orthographic neighbours demonstrates that a written word activates more than just the lexical representation by which it is represented in the mental lexicon. Besides coactivation on the basis of orthographic similarity it has been found that another type of similarity also leads to the coactivation of lexical representations, and hence affects the speed of word recognition: morphological similarity. This effect is known as the family size effect and has been discovered by Harald Baayen and Rob Schreuder (Schreuder & Baayen 1997). The title of their paper, *How complex simplex words can be,* nicely captures the essence of the phenomenon. A simple monomorphemic word like, for instance, *man,* is related to a high number of morphologically complex words that contain it as their stem or as a constituent: derivations (*manly, manhood*) and compounds (*mankind, manpower, barman, businessman, countryman, craftsman, snowman, strawman, ...*). This is the word's morphological family. What Schreuder and Baayen (1997) found – and what has been replicated in numerous studies since the publication of their paper – is that the number of these complex words (the morphological family size) affects the recognition time of the simplex word (e.g., the noun *man*). The larger the size of the family, the faster the target word is recognized. Note that inflected word forms are excluded from the morphological family, as these are merely form variants of the same word, i.e., belong to the domain of inflectional morphology, and not different words like derivations and compounds, i.e., which belong to the domain of lexical morphology.

Importantly, this effect cannot be reduced to a mere form frequency effect in disguise, resulting from a process of obligatory prelexical decomposition in the case of derivations and (possibly) compounds. If that were the case, the cumulative frequency of the morphological family members would account for the response times, whereas it does not. The family size effect is a type effect, reflecting the number of morphologically related words, not a token effect, reflecting their summed occurrence frequencies (Schreuder & Baayen 1997; De Jong, Schreuder, & Baayen 2000). Moreover, Moscoso del Prado Martin, Deutsch, Frost, Schreuder, De Jong and Baayen (2005) found that word frequency and family size were two independent factors in the prediction of reaction times to Hebrew words.

There are several reasons for believing that the effect of morphological family size reflects a high degree of connectivity among morphologically related words in the mental lexicon, and is hence a *postlexical effect.* The lexical representation of the incoming stimulus appears to propagate its activation through a morphologically organized network, such that the resulting high degree of activity leads to fast reaction times. Moreover, several strands of evidence suggest that the effect is *morpho-semantic* in nature and not purely form-based. Bertram, Baayen, and Schreuder (2000) demonstrated that removing the semantically opaque items from the morphological family increased the magnitude of the effect. Another argument against a form-based interpretation of the effect is that it also occurs for verbs that have undergone a vowel change and that are even homonyms of Dutch nouns, which should lead to the activation of the wrong family if the coactivation process were a pure form-based phenomenon. For instance, in a lexical decision experiment on verb forms like *vocht,* the past tense of *to fight* but also the homonym of the Dutch word for *moisture,* De Jong, Schreuder, and Baayen (2000) found that participants were sensitive to the morphological family size of the verb (*vechten,* to fight), despite the vowel mismatch, and not to the family of the noun, which might have been activated on the basis of the word's form. Finally, the family size effect turns up in Hebrew, a language that makes use of a non-concatenative morphology. A particularly strong indication that the effect captures connectivity within the mental lexicon, at a morpho-semantically structured level, is Moscoso del Prado Martin et al.'s (2005) finding that the morphological family size of the Dutch translation equivalents for Hebrew words predicted the RTs to the Hebrew words and vice versa. Since these are typologically unrelated languages, this finding strongly suggests that the effect of morphological family size taps into a level of representation at which the meaning of words plays a role.

6.2 The spelling process

In contrast to what is the case for the study of reading, there has been very little attention for the study of writing. The studies that have been done within the tradition of psycholinguistics or experimental language psychology have generally been concerned with the process of spelling. In a review of this literature I recently sketched the main topics of investigation in this area and the obtained insights (Sandra 2007). The research on spelling has focused on two types of spellers: those who are still in the process of learning the skill and those who have already become very good spellers. Most studies have addressed issues that are related to the process of spelling development.

6.2.1 *Spelling development*

6.2.1.1 *Stage models*

In this research area, one important question has been whether children go through a natural series of stages, each corresponding to the use of a different type of knowledge, when grappling with the task of learning a written system that encodes spoken language (at least in alphabetic languages).

The idea that there might be stages in spelling development was not obvious from the start. Treiman (1992) points out that in the sixties of the previous century people set out from the assumption that learning to spell was a form of rote learning, i.e., basically memorizing letter sequences word by word. Charles Read, studying the invented spelling of children who have not learnt to read or write yet, was the first to argue that learning to spell is a creative activity, involving the induction of underlying correspondences between letter names and their alphabetic symbol. For instance, a child that develops its own spelling system before it goes to primary school might spell the word *bay* as *ba,* because *b* represents the first sound in its letter name and the sound [ɛI] corresponds to the name of the letter *a.* His studies resulted in a book, *Children's creative spelling* (Read 1986), whose title emphasizes the importance of the learner's creativity.

After the publication of Read's work several researchers started to realize that learning to spell involves complex mental processes and that the knowledge base behind these processes changes as the child grows older. Thus the process of learning to spell began to be conceptualized as a progression through a series of stages, until adequate spelling performance was reached. Gentry (1982), for instance distinguishes five stages (we will not discuss them here), highlighting the fact that children naturally proceed from stages in which they think of spelling as the symbolic representation of the sounds they hear (the so-called semi-phonetic and phonetic stages) to stages in which they realize that there are orthographic conventions that take priority over simple sound-to-letter mappings. The general idea that children move from stages in which they encode sounds by letters/graphemes towards stages in which they rely on orthographic knowledge as well (principles and word-specific spelling patterns) has been embodied in the work of several researchers (Ehri 1997; Frith 1985; Seymour 1997).

Although the basic idea behind stage theories both sounds plausible and probably approximates the child's general learning sequence, one should be careful when using the term 'stages'. If stage models refer to a sequence of serially ordered steps in spelling development, which children must take in a fixed order, there are reasons to doubt these models on the grounds of their lack of flexibility. However, I hasten to add that, in my view, the researchers proposing stage models only attempted to mark the major developmental milestones, each being characterized by the fact that one type of spelling knowledge dominates the child's spelling performance, but not necessarily to the exclusion of other types of knowledge. At any rate, a flexible view on spelling development is certainly required by experimental data. For instance, Martinet, Valdois and Fayol (2004) discovered that after only three months of learning to read and spell, children who had to write words to dictation were better at spelling HF words like French *tête* (head) than LF ones like *toit* (roof) and more often spelled pseudo-words that sounded similar to words they could spell in correspondence with the orthographic pattern of these words *(/diRO/,* similar to *sirop,* syrup) compared to matched control pseudo-words (*/likO/).* The observed frequency effect can only mean that children store fully specified orthographic sequences for words from the very beginning of their literacy education, alongside the phoneme-to-grapheme correspondences they are taught. The analogy effect also indicates that the spelling patterns of familiar words are stored in memory, so that they can be used as exemplars for spelling novel words on an analogical basis. The authors conclude that in the initial stages of learning to spell, both "lexical knowledge and general knowledge about sound-to-spelling correspondences are simultaneously acquired." (Martinet et al. 2004, B17).

6.2.1.2 *Implicit learning of spelling principles*

Another issue when studying the spelling development of children is whether they can acquire some spelling principles by sheer exposure, i.e., through implicit learning rather than explicit instruction, and, if so, which kinds of knowledge are acquired in such an implicit way. I will discuss only one example to demonstrate that children indeed learn more about spelling than what they are explicitly taught.

The orthographic encoding of morphology is a prime example. English relies on an orthography that encodes the morphological structure of words. For instance, one spells the plural nouns *deeds* and *seats* both with a final *s,* despite the pronunciation difference of their suffix, which shows that English spelling sometimes represents morphemic units instead of sound units. It turns out that children rapidly catch on to this morphographic spelling principle, before they are even taught about it. When using a spelling completion task Treiman, Cassar and Zukowski (1994) observed that children had significantly less difficulty in spelling flap sounds that were the final sound of the stem in a morphologically complex word (*dirty*) than in a matched monomorphemic word (*duty*). A similar finding was reported by Treiman and Cassar (1996). First graders tend to omit the first of two successive consonant sounds in word-final position. However, this tendency was considerably smaller in words whose problematic sound was the final sound of the stem in a morphologically complex word than in a monomorphemic word. For instance, the letter *n* was omitted less often in words like *tuned* than in words like *brand.*

Later research indicated that the causal factor behind children's morphographic spelling was their morphological awareness, which does not necessarily imply a form of conscious awareness. Peter Bryant and his colleagues were the first to demonstrate this in a series of studies (Bryant, Nunes, & Bindman 2000; Nunes, Bryant, & Bindman 1997a,b, 2006). To measure children's morphological awareness, they administered a word analogy test that could only be solved by discovering the nature of the morphological relationship between the two words in the example (e.g., *anger-angry, strength-* ___). They discovered that children's scores on this test predicted their success in spelling regular past tenses (e.g., *filled* instead of *filld*). Similar findings were reported in French by Sénéchal, Basque, and Leclaire (2006), who compared words whose spelling was phonologically transparent (*lac,* lake), morphologically motivated (*galop,* silent final consonant, derived from *galloper,* gallop) or unmotivated and, hence, required memory retrieval (*tabac,* tabacco, with silent final consonant). Children performed better on words like *galop* than on words like *tabac,* even though both had a word-final letter that was not pronounced. However, words of the former type could be spelled by relating the target word to a morphological relative in which the stem-final letter was pronounced, thus revealing its presence (*galop-galopper*). Again a morphological awareness test showed that children who scored high on the words with a morphographic spelling (type *galop*) also had the highest level of morphological awareness. In this morphological awareness test, they had to imitate an example in which a word-final silent sound became audible by transforming the word into a morphological relative (e.g., *gris-grise,* gray; *blond-* ___, blond).

The outcome of all these experiments certainly makes sense, but should not come as such a big surprise: only children who are able to consciously reflect on morphological relationships in an analogy test are able to come to grips with spelling principles that are based on morphological insight, which also requires an awareness of morphological relations between words. However, as with so many things that seem obvious once one knows them, it is not a trivial insight. This finding can moreover explain why some children keep struggling with the spelling of these words while others move on smoothly in their spelling progress.

6.2.2 *Experienced spellers: What their spelling errors tell us*

Research on the spelling of experienced spellers is hard to find in the literature. However, the findings regarding one particular problem nicely converge across languages, at least French and Dutch.

6.2.2.1 *The effect of relative homophone frequency*

One of the most notorious spelling problems in Dutch is the spelling of a subset of regularly inflected verb forms. When thinking about it, this is strange. The spelling rules are descriptively quite simple (e.g., "add *t* to the stem when spelling the third person singular present tense", comparable to "add *-s*" in English). Moreover, there is a lot of emphasis on these rules during the entire education process (both in primary and secondary school). Finally, these errors are sometimes used to stigmatize people as being unconscientious, sloppy, non-analytical, etc. Despite this, the errors persist, even in the writings (e.g., e-mails but also final text versions) of highly educated people, like university students, journalists, professors, etc. So, what is going on that this aspect of language processing so easily derails?

Some time ago we (Sandra, Frisson, & Daems 1999) decided to identify the causal factor(s). First, it was not difficult to notice that the large majority of these errors involve homophones within the inflectional paradigm of a verb. For instance, the Dutch verb *worden* (become) is spelled as *word* in the first person singular present tense and as *wordt* ("add *-t*") in the third person. Although they have a different spelling pattern, they sound identical. The same applies to verbs like *gebeuren*, which have no stem-final *d* but are homophonous between their third person singular present tense (*gebeurt*) and their past participle (*gebeurd*). Using a speeded dictation task with 18-year-old students we found in two experiments (one focusing on the verb type *worden,* the other on the verb type *gebeuren*) that most errors were made on the lower-frequency homophone, irrespective of its grammatical function. Hence, we concluded that both inflected forms are stored in the speller's mental lexicon, that the spoken input (dictation) activates these two spelling alternatives, and that in the ensuing competition process the higher-frequency form has a higher chance of being selected under conditions of time-pressure. The implication is that the lower-frequency form is more error-prone than its higher-frequency homophone, which is what we found.

These results demonstrate the interaction between two forms of memory systems: working memory and long-term memory, more particularly, the mental lexicon. Working memory is a limited-capacity system in which information can only be temporarily retained (e.g., a telephone number) and relatively simple calculations can be performed (e.g., arithmetic operations on relatively small numbers, grammatical operations like identifying the subject of a sentence). When this limited capacity system is overloaded, either because the information that must be stored or processed exceeds the system's capacity, or because the time during which the operations must be performed is too short, the system will fail to achieve its goal. For instance, in one of our experimental conditions four words separated the inflected verb form from its grammatical subject. This was the condition where most intrusions of the wrong homophone occurred, quite likely because on many occasions the available time for identifying the sentential subject will have been too short for many participants. In the case of spelling a verb homophone a solution for this processing bottleneck is to fall back on long-term memory and select the higher-frequency spelling form. This is an unconscious process, but it minimizes the chance of making an error, as this form is the correct spelling pattern in the majority of cases (for similar results in a different task see Assink 1985).

Similar conclusions have been drawn from research on spelling errors in French (for a systematic comparison between the French and Dutch studies, see Sandra & Fayol 2003). Largy, Fayol, and Lemaire (1996) found that when a verb form and a noun are homophonous, like the French verb form *filtre* (from *filtrer,* to filter) and its homophonous noun *filtre* (filter), writers more often misspell the verb form when the noun has a higher occurrence frequency than the verb. For instance, when writing a sentence like *Le chimiste prend des liquides. Il les filtre* (The chemist takes the liquids. He filters them.) there is a high error-risk on the homophonous verb form *filtre,* which is sometimes misspelled as the noun plural *filtres.* This finding of what could be called frequency dominance in homophone spelling is quite similar to our results in Dutch, although the French study focused on homophones crossing the boundaries between lexical categories whereas we targeted homophones within the inflectional paradigm of a single verb. Note that the above French example actually reveals the effect of two error sources: the tendency to spell the higher-frequency homophone and the tendency to spell a plural where a singular is expected, at least in certain contexts. Lets briefly discuss the latter error source.

6.2.2.2 *The effect of words in the proximity*

In previous work the same authors had found that limitations on working-memory capacity enhance the risk of an error type in which spellers make the inflected verb form agree with the nearest noun rather than with its preceding grammatical subject (Fayol, Largy, & Lemaire 1994). They called these errors *proximity errors.* For instance, French spellers may write *Le chien des voisins arrivent* (the neighbours' dog arrives), spelling the plural verb form, instead of the correct *Le chien des voisins arrive.* This observation was made when participants not only had to listen to the sentence they had to write down but simultaneously had to count a number of clicks that were played together with the sentence. In other words, they spelled under conditions of working-memory overload. The fact that spellers rely on alternative sources of information when the capacities of their working-memory are exceeded ties in with our own finding (Sandra et al. 1999) on the effect of homophone frequency: this error source caused more errors when the verb form and its grammatical subject were separated by intervening words, i.e., when more working-memory resources were required.

The general conclusion from the research on spelling errors in experienced spellers is that a situation of cognitive overload causes spellers to rely on alternative information sources (relative frequency, the syntactic properties of a nearby word).

7. Spoken language processing

As I have announced in the introduction to this chapter my own research is situated in the domain of written language perception and production, which naturally implies that I am less well acquainted with all the issues that arise in the study of speech processing. Nonetheless, in what follows I will try to summarize the main issues that are discussed in the literature.

7.1 Speech perception

When listening to a speaker whose language we share (especially the native language) we seldom have the impression that we are going through a difficult process. It is as if the words are 'right there', one next to the other. What most of us fail to realize is that this is our phenomenological experience of what the speaker has said, i.e., the *end-product* of speech perception. Obviously, when all the processing work has been done, one will detect no problem. It is not difficult to demonstrate this without an experiment. If you do not happen to speak, for instance, Finnish, just listen to a Finnish speaker and try to find the words in the speech stream. You will not be able to. One might reply that this is quite obvious, as one cannot identify words that one does not know. So, lets make the task easier: identify where one word ends and another one begins, without knowing the identity of the words. You will not be able to either. You will fail because the speech signal radically differs from your perception of it as a listener in a familiar language: a grammatically ordered sequence of words. In contrast to this output representation, which gives rise to the phenomenological experience of one word sitting next to the other, the speech signal itself is a seamless, continuous flow of sound. This discrepancy is a major problem in the domain of speech perception: how is it possible that a continuous sound stream is experienced as a sequence of neatly separated words? Trying to unravel the processes that link this type of input to this type of output is one of the main challenges for researchers on speech perception. Our daily experience that linking these two is not a demanding task at all (whereas it is a puzzle to understand how it can be accomplished) underscores an essential aspect of practically all language skills: speech perception is an automatic process. We cannot prevent it from happening when someone starts speaking to us and we focus on the speaker's voice, i.e., there is no way to bring it under conscious control.

There are many important issues in this research. I will focus on two of them. How do listeners succeed in discovering the phonemes in the speech stream? How do they succeed in segmenting speech into words? Because we perform these operations effortlessly several thousands times a day, the questions sound strange. However, precisely because we perform these tasks so fluently, the seemingly obvious turns into an intricate scientific puzzle when taking a closer look at the acoustic signal we start from.

7.1.1 *Finding the speech sounds*

As mentioned above, speech is a continuous sound stream. What has been said about the absence of boundaries between words equally applies to the speech sounds in words. These are not arranged as a neat concatenation of discrete sounds. Quite on the contrary, due to the phenomenon of *coarticulation,* properties of neighbouring sounds affect each other. When uttering a word, the speaker's articulators move in a continuous manner through the oral cavity, describing the optimal trajectory that is needed to articulate the sounds contained in the word. As a result, the articulatory position for the pronunciation of a particular sound will adapt itself as much as possible to the articulatory positions of the surrounding sounds. For instance, the articulatory position of a back vowel will slightly differ when it is pronounced after a back consonant (*cook*) than after a front consonant (*took*) – the articulatory 'distance' is smaller in the former case – resulting in two acoustically different vowels. For the same reason, a front consonant will be articulated with a slightly different form of the oral cavity when a back vowel (*took*) follows than when a front vowel follows (*tick*). In other words, an optimal articulatory trajectory is the result of a mutual adaption of the speech sounds' articulatory positions to each other, which involves both anticipation and perseveration. The result is that the same phoneme leaves a different fingerprint on the acoustic signal depending on its neighbouring sounds, which implies that it cannot be recognized by looking for an invariant realization. The obvious problem, then, is how to recover the identity of phonemes amidst this large degree of phonetic variability. As Kraljic and Samuel (2005) state "For the last half century, the defining issue in speech perception research has been the 'lack of invariance' problem" (p. 167), referring to seminal research papers by the Liberman group at the *Haskins Laboratories* (Liberman, Cooper, Shankweiler, & Studdert-Kennedy 1967; Liberman, Harris, Hoffman, & Griffith 1957). Understandably, "A large body of early speech research was dedicated to the search for invariant acoustic properties of phonemes. This enterprise may be reckoned unsuccessful with respect to its ultimate goal." (Mitterer & Cutler 2006, p. 772).

7.1.1.1 *Categorical perception*

When the identity of phonemes that make up words is continuously masked by the effects of coarticulation, how then do we extract these phonemes from the signal? One plausible suggestion is that a process of normalization takes place between the phonetic input signal and the phonological representation that will be used to activate lexical representations.

The assumption behind this idea is, of course, that there are relatively stable and fixed phoneme representations, which are in turn used to activate representations in the mental lexicon. A process that seems the ideal candidate for normalizing the phonetic input is the process of categorical speech perception. Categorical perception of speech sounds refers to our ability to cut up an acoustic continuum, defined by variation on a speech-related parameter, into two discrete categories.

For instance, the syllables */ba/* and */pa/* differ along the parameter of voice onset time (VOT), i.e., the time at which the vocal cords start to vibrate. This is due to an articulatory difference between the consonants: whereas a */b/* is a voiced sound, pronounced with vocal cord vibration, a */p/* is voiceless. Hence, for the syllable */ba/* vocal cord vibration starts on average some 60 ms earlier than for the syllable */pa/,* where it starts only at the onset of the vowel. With a speech synthesiser one can create a number of */ba/* and */pa/* allophones in-between these prototypical instances, all separated from each other by a constant VOT-interval. A typical finding is that two syllable tokens with VOTs of, say, 0 ms and 20 ms are both perceived as the same syllable */ba/,* exemplars with VOTs of 40 ms and 60 ms as identical instances of */pa/,* and instances with VOTs of 20 ms and 40 ms as instances of */ba/* and */pa/,* respectively. Note that each pair of syllables has a 20 ms VOT difference. These results indicate that the mid-position between the prototypical 'human' */ba/* and */pa/,* i.e., a token with a 30 ms VOT, is treated by our perceptual system as a sharp boundary between two categories, despite the underlying physical continuum: one containing variants (allophones) of */ba/* and one containing variants of */pa/*. It has been suggested that this capacity for categorical perception makes it possible to tolerate a lot of variance in the speech signal. Categorical perception would ignore this variability and discover the phoneme category behind the phonetic token.

7.1.1.2 *Perceptual learning of category boundaries*

However, since the turn of the millennium, serious doubt has been cast on the basic premise behind the concept of categorical perception, i.e., the notion that there are stable phoneme representations in the speech processing system. Several studies have indicated that these representations are much more flexible than thought before and dynamically adapt to speaker-specific input. Most of this work has been done by Anne Cutler and James McQueen, both at the *Max Planck Institut für Psycholinguistik* in Nijmegen, and Dennis Norris from Cambridge University. The main conclusion emanating from several of their papers is that the representations onto which sounds are mapped may be phonetic in nature (rather than true phonemes in the linguist's sense of the word) and that they can quite flexibly adapt to the articulatory properties of the speaker.

In an auditory lexical decision task Norris, McQueen and Cutler (2003) presented a set of 20 words whose final fricative had been replaced by an ambiguous sound somewhere in between the */f/* and */s/* (henceforth: */?/*). In an auditory lexical decision experiment one group of participants heard words whose final */f/* had been replaced by this ambiguous sound (*witlo?,* i.e., *witlof,* chicory), whereas they also heard words with clear instances of final /s/ sounds (*naaldbos,* pine forest). In another participant group the /s/ sounds were made ambiguous but the /f/ sounds were clear (*naaldbo?* and *witlof*). At the end of the experiment, the participants had to classify the final sound in syllable tokens that were situated at the *[ef]–[es]* continuum as either an instance of /f/ or /s/, whereas the tokens were no clear instances of either sound. It turned out that participants who had previously heard the ambiguous sound in words with final /f/ classified more syllable tokens as belonging to the /f/ category, whereas those who had heard the ambiguous sound in words ending in /s/ classified more tokens as instances of /s/. Importantly, this shift of the category boundary on the phonetic continuum required that the ambiguous sound was presented in a lexical context. When it was presented at the end of nonwords, the effect did not occur. The authors' conclusion is that hearing an ambiguous sound in a lexical context makes it possible to learn which familiar sound it corresponds to, whereas this is impossible in the case of nonwords. They argue that their effect represents a case of perceptual learning, which occurs very rapidly – only 20 words with ambiguous endings were presented in a lexical decision task containing 200 items, divided equally between words and nonwords. In other words, the phonological categories that speech sounds are mapped onto before lexical access can take place are not rigid but can rapidly adapt to speaker-specific properties. This can explain our ability to quickly adapt to the peculiarities of somebody's accent.

In subsequent studies the authors reported corroborating evidence for their findings and their significance for models of speech perception. McQueen, Norris, and Cutler (2006) showed that this mechanism of perceptual learning is automatic. It also occurred when people did not have to make decisions on the experimental words and nonwords preceding the categorization task, but only had to count them. The bottom-line is again that adaptation to peculiar properties of a speech sound is a natural and automatic process.

In an important study McQueen, Cutler, and Norris (2006) demonstrated that this process not only affects category decisions but also lexical decisions on words that had not been presented in the training phase. Their rationale was that a shift of the category boundary should create a bias in the perception of words belonging to a minimal pair, when the discriminating phoneme was replaced by the ambiguous sound: participants should perceive more often the member containing the phoneme that had been replaced by the ambiguous sound in the training phase. In the experiment they made use of Dutch words and first administered the same auditory lexical decision task, including words with ambiguous consonants, as in their previous experiments. In the test phase the participants had to perform a cross-modal priming lexical decision task: they heard a word through a headphone but had to make a lexical decision on the letter string that simultaneously appeared on a computer screen. They found that ambiguous auditory items like *doo?,* which can be both *doos* (box) and *doof* (deaf) in Dutch, facilitated responses to the visual word *doos* only for participants who had initially heard words in which the ambiguous sound replaced a word-final /s/. In contrast, the same auditory items only facilitated visual lexical decisions on the other member of the minimal pair (*doof*) for participants who had initially heard words where the lexical context dictated an */f/* interpretation of the ambiguous sound. Importantly, the words in the test phase had not been encountered in the training phase of the experiment, which is strong evidence that the process of perceptual learning does not only affect the specific words in which the ambiguous sound occurred (item-specific learning) but has an effect that generalizes across the lexicon. This, in turn, is an argument that the effect does not occur at the lexical representations themselves but rather at the prelexical representations of the sounds they contain. The interface between the sensory signal and the lexical representations subserving spoken word recognition quickly adapts to speaker-specific properties, which allows listeners to generalize these properties to all words uttered by this speaker.

In another paper Cutler, Eisner, McQueen & Norris (2006) tested another prediction made by the concept of speaker-specific tuning of prelexical phonological categories: such a perceptual learning effect should be relatively stable, so that listeners can use it again when encountering the same speaker. In line with this prediction they found that listeners who had shifted their boundary between two sound categories on the basis of an ambiguous sound in the context of words maintained this shift twelve hours past exposure.

Kraljic and Samuel (2005) also demonstrated the speaker-specificity of this type of perceptual learning. In their experiments an auditory lexical decision task, in which they used ambiguous sounds that were situated in-between an */s/* and a */ʃ/,* was followed by a 25 minutes' distraction task and two sound classification tasks: one in which the stimuli were spoken by the same voice as the items in the first task and one in which another voice was heard. They made three important observations. First, participants who had been lexically guided in the first task to identify the ambiguous sound as */ʃ/* not only made more */ʃ/* responses on the */s/-/ʃ/* speech continuum than those who had been trained to interpret the sound as */s/,* the magnitude of this effect was *larger* 25 minutes after the learning phase than immediately following it. Second, this effect of perceptual learning could be annihilated, but only when two conditions were met: (i) when the same voice pronounced the */s/* and */ʃ/* sounds correctly in the intervening phase between lexical decision and sound categorization (unlearning), in a task requiring participants to select pictures on the basis of spoken instructions, and (ii) when the same voice also pronounced the items in the sound categorization task at the end. When a different voice used the correct sounds in the intervening task, no unlearning took place: the boundary shift remained in the sound categorization task, at least if the items were pronounced by the same voice as in the lexical decision task (where perceptual learning had taken place). Third, when the items in the sound classification task were spoken by a different voice than the one in the lexical decision task (male vs female), the perceptual learning effect disappeared, provided that the difference in basic acoustic properties between the two voices was sufficiently large.

Taken together, the authors argue on the basis of these results that the perceptual learning effect is relatively stable and is speaker-specific. On the one hand, the effect of perceptual learning did not disappear when a different voice pronounced the sounds correctly during an intervening task but the same voice pronounced the items in the lexical decision and sound categorization tasks. On the other hand, it did disappear when different voices pronounced the items in the lexical decision and sound categorization tasks. Apparently, listeners use subtle acoustic cues to identify a voice and use these to activate speaker-specific settings for the boundary between two sound categories when they have to categorize sounds.

Quite recently Cutler, McQueen, Butterfield and Norris (2008) reported that even sublexical information like phonotactic constraints can cause a boundary shift between categories. Presenting nonwords whose phonotactics only allowed one phonemic interpretation of an ambiguous sound made the category boundary shift in the direction of that sound. For instance, when listeners were presented with an ambiguous sound in-between */f/* and */s/* in contexts like *?rul* they learned that the sound could only be an */f/* and not an */s/*, according to English phonotactic rules, and shifted the category boundary to cover more */f/* allophones. The opposite was observed for participants who were exposed to nonwords like *?nud*, which could only be interpreted as *snud* on phonotactic grounds.

To conclude: coarticulation makes it difficult to cut up the acoustic signal of a word into a sequence of discrete sounds, but there is reason to believe that sound 'segments' in a word, even though they are not clearly delimited in the speech signal itself, are mapped onto prelexical phonetic/phonemic categories by relying on the process of categorical perception. Cutler, McQueen, Norris and co-workers published a number of studies in which they demonstrated that these categories are quite flexible and that listeners automatically adjust the boundaries between two acoustically similar phonemes on the basis of limited perceptual learning, which is triggered by degraded sound input. This adjustment can be driven by lexical or phonotactic knowledge but must be guided by information sources that enable the identification of the ambiguous sound. For that reason, the effect of perceptual learning is absent when this sound occurs in nonwords.

7.1.1.3 *Feedback from lexical representations to phoneme representations?*

The notion that lexical information can have an effect on phoneme representations is an issue that turns up in another crucial debate in speech perception research: is spoken word recognition entirely a bottom-up process, in which later processing stages can have no effect on previous ones, or is it an interactive process, making it possible that higher-level representations can provide feedback to lower-level representations, thus facilitating their identification? The crucial issue in the present context is whether there is feedback from the lexical to the phoneme level.

When replacing the sound in a word by an equally long portion of, for instance, white noise Warren (1970) found that listeners did not hear there was something wrong with the word and could not identify which sound had been replaced by something else when asked to do so. It was clear that 'something' restored the missing phoneme in listeners' perception.

Using signal detection techniques Samuel (1981, 1987) argued that this effect of phoneme restoration was caused by the lexical context on the basis of lexical-to-phoneme feedback. As a result, the effect was not the outcome of educated guessing on the basis of the available sounds, but was truly perceptual in nature, a perceptual illusion. However, the issue is far from settled.

Samuel (1996) admitted that some studies did and others did not find a perceptual effect of phoneme restoration. Using a sensitive technique he could demonstrate that the effect is real, though fragile. One year later (Samuel 1997) he reported a series of experiments in which he strongly argued in favour of the interactive position, i.e., feedback from the lexical to the phonological level of representation. In this paper he used the adaptation technique. Technically, a participant in such an experiment has to perform a phoneme categorization task (e.g., on the */g/-/k/* continuum), is then exposed repeatedly during the so-called adaptation phase to a stimulus (the adaptor) one of whose sounds matches an extreme on the sound continuum (e.g., *gift*), and is then again confronted with the same items as in the first sound classification task. The effect is a boundary shift between the two sound categories. For instance, if the adaptor is voiced fewer test items will be identified as voiced than in the first classification task.

After demonstrating that using long words as adaptors (involving the */b/-/d/* continuum) caused an adaptation effect he showed that a (reduced but quite significant) adaptation effect also emerged when the target sound was replaced by white noise but not, crucially, when it was replaced by silence. Hence, stimuli that create an auditory word illusion behave like real words in the adaptation paradigm. In line with this effect, he found adaptation effects with nonwords that were highly similar to words (hence, caused lexical activation) but not with nonwords that were dissimilar to words. Finally, he found that the adaptation effect did not differ between words (*gift* and *kiss*) and nonwords (*kift* and *giss*) as adaptors. This, he argued, demonstrated that the adaptation effect from word adaptors causing perceptual illusions had its locus at the level of phoneme representations and was, hence, mediated by the lexical level through a feedback mechanism. Accordingly, the conclusion is that the effect of phoneme restoration is a perceptual effect: participants have the same perceptual experience, whether the target phoneme is present or replaced by, for instance, white noise. (for another series of experiments leading to the same conclusion see Samuel 2001).

A radically different point of view is adopted by James McQueen and colleagues. In two recent papers (McQueen, Norris, & Cutler 2006; McQueen, Jesse, & Norris 2009) they strongly argue against feedback from the lexical to the phonemic level. McQueen et al. (2009) argue against a phenomenon that has been taken as solid evidence in favour of lexical feedback to the phonemic level in online speech perception: the so-called perceptual compensation for the fricative-stop coarticulation. Lets first explain the concept of fricative-stop coarticulation, which dates back to the experimental work by Mann and Repp (Mann & Repp 1981; Repp & Mann 1981, 1982). These researchers found that an unambiguous fricative like */s/* or */ʃ/* determines the interpretation of a following ambiguous sound in-between the */t/* and the */k/*: a */s/* gives rise to a */t/* interpretation, whereas a */ʃ/* creates more */k/* responses. The investigators attributed this phenomenon to coarticulation effects: the position of the lips when articulating an */s/* (spread) more closely resembles the position for a */t/* than that for a */k/* whereas the reverse obtains for the lip position when pronouncing */ʃ/*, which more closely resembles that for */k/* (both rounded) than that for */t/*. Elman and McClelland (1988) linked this coarticulation phenomenon to the notion of perceptual compensation. They made both the word-final fricative and the following word-initial plosive ambiguous, presenting auditory inputs like *fooli? *apes* and *Christma? *apes* (where *?* and * indicate the ambiguous sounds). They reasoned that if the lexical information in the first word provides feedback to the phoneme level, the */ʃ/* sound would be identified in the stimulus *fooli?* and the */s/* sound in the stimulus *Christma?*. Due to the phenomenon of fricative-stop coarticulation, which must be a prelexical mechanism in their view, the * in **apes* would be heard as a */k/* when preceded by *fooli?* but as a */t/* when preceded by *Christma?,* which is exactly what they found. They concluded that the prelexical coarticulation effect could not have occurred if there had been no prior feedback from the lexical to the phoneme level. However, McQueen et al. (2009) report experiments in which they demonstrate that this technique, particularly in a study reported by Magnuson, McMurray, Tanenhaus, & Aslin (2003), creates bias effects that are induced by the experimental materials rather than effects demonstrating the operation of a feedback mechanism.

McQueen et al. (2006) succinctly summarize the work on the long list of experiments that have been performed to study the effect of lexical representations on prelexical phoneme representations. They argue that the evidence supports lexically-based retuning of phoneme boundaries in a learning procedure (perceptual learning on the basis of ambiguous sounds) but is thus far unclear as far as the existence of online lexical-to-phoneme feedback effects is concerned: "The evidence on whether there is on-line lexical influence on prelexical processes is thus inconclusive. However, consensus has been reached on the existence of lexical feedback for learning." (p. 533). To support their latter statement they refer to their own Norris et al. (2003) study and the study by Kraljic and Samuel (2005) discussed above.

7.1.2 *Finding the words in a sentence*

Another vexing problem in the study of speech perception is how listeners succeed, without any conscious experience of difficulty, in segmenting a spoken sentence into its constituent words. As mentioned before, the speech signal is a continuous stream of sound with no physical gaps between words (e.g., short silences) to mark the boundary between words. There is seldom a physical boundary between words, and the observable 'gaps' on a spectrogram often fall within the boundaries of a word, making them unreliable segmentation cues. So, how do listeners solve the problem? The answer is that they have access to several types of information that can be used as segmentation strategies.

7.1.2.1 *The importance of the rhythmical heuristic*

A major strategy, which has received a lot of attention in the literature, is the so-called rhythmic strategy. When acquiring their language, children seem to adapt to the rhythmic properties of their spoken language input rather than adopting a universal segmentation strategy. The first to demonstrate sensitivity to these rhythmical properties of the native language were Jacques Mehler and his co-workers in France (Mehler, Dommergues, Frauenfelder, & Segui 1981). They showed that participants detected a sound sequence like *pa* or *pal* that was embedded in a target word faster when that sequence matched the first syllable in the presented word, irrespective of the phoneme length of the sequence. For instance, in French words like *palace* (palace) the sound sequence *pa* was detected faster than the sequence *pal*; in contrast, in words like *palmier* (palm tree) the sound sequence *pal* was detected faster than the sequence *pa*. The authors' explanation was that French is a syllable-timed language, i.e., its syllable boundaries are very clear, and that such a language invites listeners to cut up the speech stream in a series of syllables, which are then used to recognize words.

Research in other languages confirmed this language-specific segmentation strategy. From a rhythmic perspective, English radically differs from French. French has clearly defined syllables whereas English is plagued by the problem of ambisyllabicity (how do you syllabify *missile:* as *mis-sile* or *mi-sile?*). However, English has another reliable rhythmic property: the majority of its words begin with a strong syllable (i.e., non-reduced vowel). Cutler and Carter (1987) used two computerized dictionaries to find out that the number of lexical English words (i.e., omitting function words) beginning with a stressed syllable was three times as large as the number of words beginning with an unstressed syllable. Additionally, words with a strong initial syllable have a higher occurrence frequency in the language. Together, these two phenomena are responsible for the fact that about 85% of the word tokens one hears in English speech have a strong initial syllable. Cutler and Carter actually counted the number of word tokens with this metrical pattern in a 190,000 word token corpus of spontaneous conversation and indeed found that 90% of the tokens had a word-initial strong syllable.

This lexical-statistic property of English allows for an ideal word segmentation heuristic: each strong syllable is a potential word beginning. Cutler and Norris (1988) reported evidence that native speakers of English indeed rely on this heuristic. They embedded an existing one-syllable word (e.g., *mint*) at the beginning of a nonword and compared a condition in which the second syllable was also stressed (e.g., *mintayve*) with a condition in which this syllable was unstressed (e.g., *mintesh*). The participants had to spot the embedded word. They were faster when the second syllable was unstressed. According to the authors, two stressed syllables induce a segmentation within the nonword because each stressed syllable is a potential word beginning. This makes it necessary to integrate the first phoneme from the second syllable (*t* from *tayve*) with the first syllable (*min*) to spot the target (*mint*), which is not required for items with a weak final syllable, as these are not segmented. This finding supports a stress-based segmentation strategy for English.

This result was corroborated by Cutler and Butterfield (1992), who created word sequences that were in conflict with the typical distribution of strong and weak syllables in English, in an attempt to show that such sequences would induce missegmentations on the part of the participants. For instance, in a sequence of three words with the atypical weak-strong pattern (e.g., *conduct ascends uphill*) a stress-based segmentation strategy would predict that the strong word-final syllables trigger a segmentation attempt within the words and, hence, signal the beginning of a possible word at the wrong place, leading to misperceptions of the word sequence. This is indeed what happened: often participants reported having heard sentences like *the doctor sends her bill,* a sentence that contains three words with a strong initial syllable, as one would expect if English listeners treat each stressed syllable as a possible word beginning.

Several other studies in different languages were in line with the general idea that listeners 'tune in' to the language-specific rhythmic properties. For instance, Otake, Hatano, Cutler, and Mehler (1993) found that the Japanese mora, which determines the rhythmic pattern in the Japanese language, was used as a cue for segmenting a sentence into candidate words. With respect to Dutch, Vroomen, van Zon, & de Gelder (1996) also reported evidence for stress-based segmentation. They reasoned that it was not only important to compare languages with different rhythmic structures but also languages with identical structures (such as English and Dutch). The concept of rhythm-induced segmentation predicts that such languages should show similar properties. And indeed, this turned out to be the case. Dutch, which resembles English in its preference for words with strong syllables in initial position, behaved as English had done in the earlier studies by Cutler and colleagues (although the authors suggested a second information source for segmentation, see below).

Taken together the evidence forms a coherent picture. However, what would happen when speakers of one language (say, English) have to perform a monitoring ask in a different language (say, French)? Would they automatically catch on to the rhythmic structure of the language or would they adhere to the heuristic they have learnt for their native language? A theoretically important distinction is, moreover, whether the answer to this question will differ for monolingual and bilingual speakers. The almost obvious hypothesis is that monolinguals will be unable to swith to the other-language pattern (which they are unaware of) whereas bilinguals will swiftly adapt to the rhythmic structure of each language. However, the answer to the question was not so simple, which explains why the experimental results did not only find their way into the psycholinguistic literature but also in the highly renowned journal *Nature.*

Cutler, Mehler, Norris & Segui (1983) came up with a brilliant idea: to tease apart the role of the language and the role of the listener in sentence segmentation one could confront monolinguals, who have adopted a language-specific segmentation strategy, with a language that requires a different type of segmentation. Will such listeners stick to their familiar strategy or adopt a strategy that is tailored to the new language? So, they presented the French materials from an earlier study to a group of English students with a very limited knowledge of French, and the English materials from an earlier study to a group of French students with a limited knowledge of English. The task was the same kind of monitoring task used in previous studies (e.g., press the button if you hear a word that begins with *pal*). The researchers found that monolingual speakers do not capitalize on the rhythmic structure of the new language. They cling to their own one, such that the English students monitoring French materials showed the same pattern of results as English students monitoring English materials. Also French speakers used their syllable-based segmentation strategy on English, even though it did not fit the structure of that language. They, too, showed the same pattern of results as the group of French listeners who were confronted with their native language. In other words: the native language imposes a segmentation strategy on listeners, which they rigourously apply to another language, even when its rhythmic structure does not lend itself to this strategy. (see Cutler, Mehler, Norris, & Segui, 2002, for a similar set of results).

The same authors (Cutler, Mehler, Norris, & Segui 1989) published a letter in *Nature,* in which they raised the same question – Is the segmentation strategy determined by the listener or by the rhythmic properties of the linguistic input? – but used a different population this time: bilinguals who mastered French and English almost equally well and were accepted as native speakers in both speech communities. Still participants were forced do identify their favourite language by replying to the question "if you had to lose one of your languages to save your life, which would you keep?" (p. 229). The answer to this question was used to classify them as English-dominant or French-dominant. One might expect that balanced bilinguals like these have become tuned to the rhythmic structure of the two languages. However, this is not wat the results showed.

English-dominant speakers used their metrical heuristic for both languages. Despite their extremely high skill in French they apparently could not use its syllable-based segmentation strategy. In contrast, the French speakers used the syllable-based strategy for French and the metrical strategy for English. The authors conclude that, despite being a very good bilingual, one language remains the dominant one: English-dominant bilinguals could not apply a syllable-based strategy to French. In order to explain the dissociation between English-dominant and French-dominant bilinguals, the researchers appealed to the concept of markedness. They argued that the syllable-based rhythmic structure of French is a marked (exceptional) case, since many languages share the metrical structure of English. In their view, someone who is good at using the marked structure (French-dominant speakers) can easily switch to the use of the unmarked structure but someone who is good at using the unmarked structure (English-dominant speakers) is not able to adapt to the marked, syllable-based structure of his other, near-native language. They claim: "Our present study suggests that at this level of language processing there are limits to bilingualism: a bilingual speaker has one and only one basic language" (p. 229).

The prominent role of rhythmic structure in cutting out the words from a spoken sentence seems to be deeply rooted in very early language development. In the early eighties of the previous century Bertoncini and Mehler (1981) demonstrated that the syllable is particularly attractive to very young infants younger than two months (the average age in each group was below 40 days). Over a headphone they played either a CVC (i.e., phonotactically possible syllable, e.g., *pat*) or a CCC (i.e., phonotactically impossible but pronounceable because the medial C was a fricative, e.g., *tŠp*) to the infants. They used the habituation procedure by monitoring the sucking rate of the infant during continuous presentation of the same syllable, treating the sucking rate as an index of the infant's interest. What interested them was how the sucking rate would be affected when switching to a different auditory stimulus, made by swapping the initial and final consituents (e.g., *pat* became *tap* and *tŠp* became *pŠt*). The percentage increase in the sucking rate following this switch was larger for true, CVC syllables than for CCC sequences. They concluded that, in French, the syllable is a basic unit in speech perception.

Even though the Bertoncini and Mehler (1981) study highlighted the importance of the syllable, which ties in with the later discovered important role of the syllable in the segmentation of French, Jusczyk, Cutler and Redanz (1993) targeted young children's sensitivity to the rhythmic structure of their language more directly. They were curious whether young children were already sensitive to the stress-based structure of English, more particularly, the dominance of the strong-weak (SW) pattern in word-initial position. Children aged 9 months heard either a list of SW or a list of WS English words through a loudspeaker. Examples of such lists are: *pliant, falter, donor, comet, neighbour, butter, final, stalwart, gentle, sinus, rhesus* (SW) and *comply, befall, condone, comport, pomade, abut, define, restore, resent, assign, caprice* (WS). A flickering red light was situated at the loudspeaker position when the list was being played. The rationale of this so-called headturn procedure is that, as long as the child keeps watching the red light she/he is apparently interested in the words coming out of the loudspeaker, wheras turning its head away is a sign of a loss of interest. The authors found that 9-month olds were more interested in SW lists than in WS lists, which is in line with adults' preference for a metrical segmentation procedure in English. In contrast, 6-month olds did not show this preference, ruling out an interpretation that the difference was due to the SW patterns being acoustically more attractive rather than to a preference for the dominant stress pattern in the language. Finally, when the same word lists were again played to 9-month olds but the words had gone through a low-pass filter, such that only suprasegmental information like stress remained, the children again preferred the SW stimuli. This evidence clearly demonstrates a very early sensitivity to the basic rhythmic structure of the language, a type of knowledge that will later turn out to be quite useful when they have to segment sentences in words.

7.1.2.2 *The contribution of lexical competition*

Despite the fact that relying on the language's dominant rhythmic structure is a big help in finding the word boundaries in a spoken sentence, it cannot be sufficient to find all words. Recall that in English, for instance, about 10% of the word tokens that speakers daily encounter do not match the dominant stress pattern, i.e., are WS words. Hence, other knowledge sources must be involved as well. One of these sources is the principle of lexical competition.

Since thousands of words in the vocabularies of languages like English are constructed from a small set of some 30 phonemes, it is statistically unavoidable that many words will contain identical phoneme sequences, even phoneme sequences that occur as words in the lexicon but do not function as a word (morpheme) in the longer word in which they are embedded. For instance, the phonological sequences for the words *scan, can,* and *candle* all appear in a spoken word like *scandal.* McQueen and Cutler (1992) found an average of 2.6 embeddings per word, when only counting embeddings whose boundary coincided with that of the carrier word (e.g., *scan* was counted as an embedding in *scandal*, but *can* and *candle* were not). Considering all English polysyllabic words McQueen, Cutler, Briscoe and Norris (1995) found that 84% contained embeddings. Cutler, McQueen, Baayen and Drexler (1994) found that 71.1% of the words in a real-speech corpus of English contained embedded words whose syllable boundaries were aligned and 92.3% when these boundaries were ignored.

When the spoken input is so ambiguous with respect to the identity of the words, how can listeners ever identify the right words in the speech stream? The solution that all current models of spoken word recognition embody is the notion of competition in a lexicon in which multiple candidates are activated by the spoken input (McQueen & Cutler 2001). The idea is simple: activated word representations inhibit the activation level in the representations of other activated candidates with a strength that is proportional to their frequency. In the case of *scandal* there will be parallel activation of all words whose phoneme structure is present in the signal: *scan, can, candle* and *scandal* itself. The competition among these word candidates will be proportional to their frequencies but the lexicon will also (have to) take into account whether the phonological sequence of the 'winning' candidate aligns completely with the input. Thus the competition process will result in the recognition of the word *scandal* because all other word candidates cover only part of the input and no combination of two candidates aligns with the input (e.g., *scan+candle* does not match *scandal*).

7.1.2.3 *The possible word constraint*

Research by Norris, McQueen, Cutler and Butterfield (1997) has shown that the competition process is constrained by an additional principle: the Possible Word Constraint (PWC). This constraint was formulated to account for the observation that, for instance, people find it harder to recognize the word *apple* in a spoken input like *fapple* than in one like *vufapple.* The PWC states that listeners will not segment a word such that a vowelless residu is left between an embedded word and the nearest word boundary. Indeed, in the example above, *f* could not be a word, which makes it impossible that *apple* is an internal constituent, whereas *vuf* might in principle activate a word or be sufficiently similar to stored words, such that *apple* must temporarily be treated as a possible word candidate. Cutler, McQueen, Jansonius, and Bayerl (2002) made a lexical-statistic analysis of the English and Dutch lexicons, as assembled in the CELEX database, which contain all words in the language, drawn from a representative corpus of texts together with their occurrence frequency (among many types of orthographic, phonological, and syntactic information). The English database comprises 70,000 words and is based on a corpus size of 17.9 million tokens, whereas the Dutch database has a total of 280,000 words based on 42.4 million tokens. In line with previous studies the authors found that only a very small minority of words did not contain an embedded other word (English: less than 2%, Dutch: less than 1%). The crucial part of the study was, of course, whether taking the PWC into account to constrain the process of lexical competition would be beneficial. The answer for both languages was a clear yes. In English, the ratio of embeddings leaving a vowelless residu (PWC violations) to those leaving a possible word was 1.56 to 1. Including the occurrence frequency of these words in the calculations brought the ratio to 2.69 PWC violations to 1, which amounts to a saving of 73% (i.e., 2.69/(2.69+1)). A similar picture emerged in Dutch: 1.28 PWC violations to 1 non-violation in a type-based count, 1.54 violations to 1 in a token-based count, which amounts to a saving of 61% (i.e., 1.54/(1.54+1)). Note that the figures in Dutch are smaller because this language makes abundant use of compounding, which diminishes the proportion of vowelless residues. The authors conclude that taking the PWC into account would remove the majority of spuriously embedded words like *ample* in *sample*.

7.1.2.4 *Reliance on statistical regularities*

Another information source that is likely to guide the parsing of a sentence into words is the language user's knowledge about the co-occurrence probabilities of phonemes, or the probability that phoneme x will be followed by phoneme y (transitional probability, TP). In the extreme case, TP will have the value zero, which means that these two phonemes cannot co-occur in a word and that, hence, a word boundary can be postulated (or a morpheme boundary, as in *handbook,* but we will not go into this issue now).

However, not all phoneme pairs have a TP of 0. Some are more likely than others and unlikely co-occurrences could be used to postulate a possible word boundary in-between the phonemes. As it happens, it has been shown that even 8-month old babies already rely on such statistical information to chop out the words in a continuous speech stream. Saffran, Aslin, and Newport (1996), in a study reported in *Science,* reported two ingenious experiments with 8-month old infants. They reasoned that on average the TP between two phonemes will be lower when they straddle a word boundary than when they co-occur within a word. In principle, these lower TP values could be a useful heuristic for postulating word boundaries in the continuous speech signal. Saffran et al. wondered whether 8-month old infants would already be sensitive to TP information.

They made up four nonsense words, each consisting of three syllables (*tupiro, golabu, bidaku,* and *padoti*). The babies were exposed to a continuous speech stream of 2 minutes in which these four 'words' were repeated in random order. A speech synthesiser with a female monotone voice generated the speech stream at a rate of 90 words per minute, such that each word appeared 45 times over the course of the 2 minutes' training phase. The generated signal contained "no acoustic information about word boundaries, resulting in a continuous stream of coarticulated consonant-vowel syllables, with no pauses, stress differences, or any other acoustic or prosodic cues to word boundaries" (p. 1927). In the test phase the children were exposed to two of the words that had been embedded in the speech stream (*tupiro, golabu*) and to two nonwords, consisting of syllables that had never co-occurred in the training phase and were taken from at least two different words (*dapiku, tilado*). Accordingly, the TP value between the syllables in the words was 1 whereas it was 0 in the nonwords. Using the headturn procedure (flickering red light) the researchers found that the infants showed significantly more interest in the novel items than in the familiar ones (a difference of about 1 sec).

The second experiment was even more challenging for the infants. They were again familiarized with four three-syllable words (*pabiku, tibudo, golatu,* and *daropi*) in the learning phase. Each word was presented 45 times and it followed each of the other three words 15 times, such that the TP value between each word-final syllable of a word and each word-initial syllable of the three other words was 0.33. In the test phase the babies heard two familiar words (*pabiku, tibudo*) and two nonwords, each of which was made by recombining the syllables of the untested familiar words, more particulary, by taking the final syllable of one of these words and stringing it together with the first two syllables of the other one (*tudaro, pigola*). Notice that the TP distributions in the words and nonwords made the discrimination task considerably more difficult than the previous one: the two TP's in the words were 1, those in the nonwords were 0.33 and 1. Yet the babies again showed significantly more interest in the nonwords than in the familiar words (again, a difference of about 1 sec).

Saffran et al.'s observations demonstrate the power of young children's inductive learning through the estimation of statistical regularities in the data, even within an interval as short as two minutes. They can use this knowledge to discriminate familiar syllable sequences from unfamiliar ones, suggesting that also adult listeners may rely on statistical knowledge about the phonological material that co-occurs in the sentences of a language for segmenting the spoken language stream into words.

As an aside, albeit not a trivial one, the authors finish their paper by situating their findings in the context of the language innateness debate: "some aspects of early development may turn out to be best characterized as resulting from *innately biased statistical learning mechanisms rather than innate knowledge*." (my emphasis) Their own, further research along the same lines more and more suggests that they may have an important point (see the introductory contribution to this volume for more discussion on their work: Perspectives on language and cognition).

7.1.2.5 *Reliance on subtle acoustic cues*

Finally, there is evidence that suble phonetic differences can assist listeners in their segmentation task. Spinelli, McQueen, and Cutler (2003) studied the effect of liaison in French, more particularly in contexts where the liaison gave rise to lexical ambiguity, as in *le dernier oignon* (the last onion), where the process of resyllabification makes the first word's final consonant form a combination with the next word, making it homophonous to the word *rognon* (kidney), as in *un demi rognon* (half a kidney). In cross-modal priming experiments participants first heard a French sentence, containing a phoneme sequence that was lexically ambiguous due to the possible liaison between a word-final consonant and a subsequent word-initial vowel (*C'est le dernier oignon/rognon;* it is the last onion/kidney). At the offset of the spoken sentence the target word *oignon* or *rognon* appeared on a computer monitor and a lexical decision had to be made. Facilitation effects were found on the vowel-initial words when they had been intended by the speaker (e.g., *oignon* in *le dernier oignon*), despite the fact that resyllabification resulted in a homophonous consonant-initial competitior (*rognon*). Facilitation effects on non-intended vowel-initial words (e.g., *oignon* in *le dernier rognon*) were not absent but weak. How could listeners tell the difference between the intended and non-intended words in a situation of homophony? The authors measured the length of the consonant that was responsible for the ambiguity and found that its duration was shorter when the vowel-initial word was intended (between 10%–18% difference). These findings suggest that the acoustic signal contains subtle acoustic cues (like durational differences) that listeners can use to make the segmentations that match the speakers intentions. The authors refer to earlier findings by Gow and Gordon (1995), who found that a word like *lips* was activated in two-word contexts like *two lips* but not in one-word contexts containing the phonetic sequence of the word (*tulips*). These authors, too, observed that the duration of the /l/ was longer in word-initial position, which is in line with Spinelli et al.'s finding that the word-initial /r/ was longer when the consonant-initial word was intended. In short: subtle acoustic differences can help listeners in their segmentation attempts as well.

7.2 Speech production

Needless to say, speech production is the pivotal language ability. Without our ability to speak, there would simply be no need to explain speech perception, as there would be no speech. Similarly, there would be no need to study reading and writing (spelling), as the written code for words is secondary to what is a species-specific skill, due to our human genetic set-up (which is clearly not equivalent to the claim that there is an innate set of grammatical principles, as is the case in Chomkyan linguistics). Still, despite the crucial nature of speech in human verbal communication, studies of this process represented the minority of psycholinguistic research for a long time, although this is no longer the case. Speech production research can be divided into two eras: one in which researchers attempted to infer the design underlying this skill from speech errors and one in which experimentation has taken over to study this process.

7.2.1 *Speech error research*

One of the biggest problems to study speech production processes has to do with the fact that the stimulus that initiates the process is an internal one, more particularly, a message that somebody wants to convey to somebody else. The only observable aspect of speech is its end product, when all relevant mental processes have been performed: the spoken sentence. This stongly contrasts with research on reading and speech perception, where the experimenter has full control over the stimuli that are presented for processing and where careful manipulations of factors that are deemed important leads to the creation of material sets that can easily be related to, for instance, RT and error measures.

The problems with manipulating an internal stimulus is without any doubt an important reason why early researchers of the speech production process focussed on the observable output. At first sight, it would seem that spoken sentences are uninteresting from the perspective of somebody who is interested in the mental architecture that makes the generation of these sentences possible. This architecture cannot be read off the spoken sentences. Or can it? The early investigators of speech production must be credited for realizing that, indeed, this architecture leaves different kinds of fingerprints on some spoken sentences, and that good 'detective' work could lead them to the identification of the hidden process that was responsible for each type of fingerprints. The fingerprints in case are speech errors, those instances when the process of speech production fails and results in an error.

The logic of collecting naturally occurring speech errors and systematically studying them to arrive at a theory of speech production has a straightforward logic. Any system has a structure (be it a car, a thermostat, a text processor, or a speech production system) that seriously constrains the possible operations that the device can perform. Due to this very same structure it also sets limits on the types of errors that it can make. For instance, a thermostat's components have been designed in such a way that its function is to keep the room temperature at the programmed temperature. When we come home and observe that the temperature is much too high, we will infer that the thermostat has a defect. Theoretically, the cause is probably easily identified. At the level of its internal structure the thermostat must have a device that constantly measures the room temperature and compares it to the value set by the user. When the temperature is too low, this device gives a signal to the central heating that it must switch on. When the temperature is too high, the device sends an 'off' signal, such that the central heating stops producing more heat. Now, several things can be broken when the thermostat does not function: the device itself or its communication with the central heating (the central heating itself can be excluded because it is too warm, so it works fine). When the device itself is broken, the defect can be either a failure in the component that measures the room temperature, a failure in the comparison with the preset temperature, or (trivially) empty batteries. When this device works well, the defect is in the communication with the central heating system, which may be situated either at the beginning or the end of this transmission: the thermostat may no longer transmit the signal or the central heating may receive the signal but no longer respond to it. Now, I know nothing about thermostats or central heating systems but it is clear that this kind of reasoning may help diagnose the problem and that any of these possible error-causing components must be part of the stucture of the thermostat.

The purpose of this digression is to show that when a device malfunctions (makes an error) a systematic analysis may help you uncover its internal structure and the way it operates. You will not be able to sketch the design behind the device at a microscopic level (e.g., the microcircuits in the thermostat) but you will be able to discover the large-scale internal architecture that it must have in order to function the way it does. Moreover, the nature of its errors will suggest components in its design that are likely to malfunction. The bottom-line is this: the structure of a device allows certain errors and makes others impossible (the design of a car makes it possible that it will miss a curve in the road but makes it impossible that it will fly; an airplane can fly but cannot drive backwards). Through a systematic study of the errors that occur one can arrive at the identification of what has gone wrong inside its internal architecture and thus reconstruct this architecture.

This is the rationale behind the study of speech errors by the early practitioners (Fromkin 1971, 1973; Garrett 1975; Nooteboom 1967; Shattuck-Hufnagel 1979). Assemble a corpus of speech errors, analyze them systematically by trying to identify what may have gone wrong, make a taxonomy of different types of malfunctions, and, finally, integrate all thus identified speech production components that have been derived from the errors into a model of human speech production. This is an example of clean reasoning in a time when current-day experimental procedures were unavailable to study the speech production process more directly.

I will not dwell too long on speech error research and soon turn to the modern techniques. However, it would be unfair to pass over the influential literature on speech errors that dominated the research on speech production for at least two decades and still leads to the publication of papers. The pioneer on the use of speech errors to discover the design of the human speech processor was Victoria (Vicky) Fromkin (1973), who wrote a book whose title is self-explanatory: *Speech errors as linguistic evidence.* Still in what follows I will focus on Merrill Garrett's contribution to this literature.

The model that Garrett (1975) designed already contains many ingredients of the current-day models, even though it is a box-and-arrows model that was typical of that time. At the message level the speaker decides what to say about whom or what. This content selection sets a whole series of processes in motion, which will ultimately lead to the articulatory movements that transmit the message to the listener. Crucially, in Garrett's model there are two grammatical levels: the functional level and the positional level. At the former the abstract grammatical information on the appropriate lexical items is retrieved and the syntactic relations among these items are determined (e.g., subject, objects). Among the abstract grammatical information of a word belongs its word class (noun, verb, …) but also its semantic information. Semantic substitution errors like *He rode his bicycle tomorrow* (yesterday) originate at this level.

At the functional level the phonological form has not been retrieved yet. That only happens at the positional level. At this level, a series of processes takes place. The phonological form of the lexical items is retrieved, as can be derived from phonological errors like *his immoral soul* (immortal). Additionally, the grammatical information retrieved with the lexical items at the functional level is now used to plug the phonological forms of the words into their appropriate slots in the syntactic frame of the sentence, slots that are also labelled for syntactic category. It is at this stage that word exchange errors occur, like *I must let the house out of the cat* instead of *I must let the cat out of the house*. As the example shows, words can exchange positions when the mechanism that allocates word forms to positions in the syntactic frame is confronted with two words sharing the same syntactic category and two sentential slots marked for this same category (which is why most of these exchange errors involve two words of the same syntactic category, i.e., nouns generally exchange with nouns, verbs with verbs, etc.). Note that the occurrence of word exchange errors reveals the existence of such a process of word-to-sentence-position assignment. The distance over which such exchange errors occurs has been used to estimate the number of words speakers plan ahead when uttering a sentence.

Such exchange errors reveal a remarkable phenomenon: when two words exchange places in the sentence the morphosyntactic information associated with these words does not migrate together with the words. For instance, in the speech error *I'd hear that if I knew it* (correct: *I'd know that if I heard it*) the words *hear* and *know* have exchanged places but the grammatical encoding of past tense has not: the form *heard* did not move, only its infinitive. Its past tense marker remained at its proper place and was applied to the migrated word *know,* that moved into the slot where the verb *hear* should have been. The take-home message is that there is a processing level at which the phonological form of the lexical words is already available and linked with its position in the sentence frame, but the morphosyntactic information that is linked to this same positional slot is still represented in an abstract format (e.g., past tense, plural suffix). Only in a later processing stage, this abstract information will be 'translated' into a contextually appropriate phonological form, i.e., be adapted to the phonological form inserted into the slot. A bound morpheme (or, rather, its underlying morphosyntactic specification) that remains stuck at its original sentence position whereas the word that it should be attached to migrates to a different sentential slot and is replaced by a different word, is known as a morpheme stranding error.

Besides retrieving the phonological form of words and putting the words in their correct linear order, the positional level finally contains a process that puts the phonemes within a word in their correct order. The latter process occasionally derails as well, producing a so-called phonological error. Such errors are misplacements of phonemes, which implies that the phonological structure of a word is not an undivided whole, but rather a sequence of neatly ordered phonemes, which can also be misarranged. Consequently, in a sentence context they can migrate away from the correct position within their word. There are many different types of phonological errors: anticipation errors, like *leading list* instead of *reading list,* where the first phoneme of the first word has been replaced because the speaker anticipates the first sound of the following word. There are perseveration errors, like *waking wabbits* instead of *waking rabbits,* where a phoneme is repeated in a later slot, replacing the correct phoneme. Phonemes can also exchange places, as in *some swummers sink* instead of *some swimmers sunk.* Phoneme exchanges in word-initial position that cross word boundaries, as in *heft lemisphere* for *left hemisphere* or *God is my shoving leopard* for *God is my loving shepherd,* are known as a separate variety. They are called Spoonerisms, after the reverend Spooner, who is said to have made this type of speech error quite frequently.

Once the order of the words within their grammatical frame and the phonemes within their word frame have been specified the sentence is ready to be 'sent on' to the phonetic level, where the phonetic realization of the abstract phonological structure takes place. At this level, errors that have been made when arranging the phonemes can cause phonetic accommodations, just like erroneous word insertion errors at the positional level caused allomorphic accommodation or morpheme stranding errors. For instance, the error *an unkey's muncle* (intended: *a monkey's uncle*) shows that a phoneme movement error at the previous processing stage makes the indefinite article appear before a vowel-initial word. A phonetic process turns the intended form of the article, *a,* into the form *an,* thus adapting it to the erroneous phonetic environment.

Finally, this phonetic sentence representation is recoded into an articulatory representation of the sentence, i.e., a specification of the motor gestures that are required by the articulators in the vocal tract to actually utter the sentence.

7.2.2 *Experiments on speech production*

Despite the unmistaken value of speech errors for models of speech production, their easy accessibility in naturalistic conditions (any conversation on any day), researchers in the eighties of the previous century have started to devise techniques that make it possible to tap into the processing of speech production in real time, i.e., while it is going one. Indeed, there are a few disadvantages to the study of speech errors that can be compensated for by the use of online techniques. First, they are offline data. They are the product of the speech production process and, hence, only indirectly shed light on the underlying processes that make speech production possible. Second, one might get the impression from the speech error literature that speech production is a highly error-prone process and that errors abound. The contrary is true. Levelt (1992) refers to a study by Garnham, Shillcock, Brown, Mill, and Cutler (1982) in which they analyzed a corpus of spoken text consisting of 200,000 word tokens and counted 86 lexical selection errors and 105 other slips of the tongue, which means that in the process of speech production, we make, on average, only one error per 1,000 spoken words. This testifies to the high reliability of this process and at the same time underscores the fact that speech production models that are based on speech error data depend on only 1% of the data in natural speech. Needless to say, a scientific model that is built on what is the exception runs the risk of being wrong or at least incomplete, even though the underlying rationale behind speech error analysis is plausible and hard to refute.

For these reasons, it became increasingly clear to researchers that the error-based analyses and models had to be complemented by data obtained in paradigms where correct speech was studied while taking place in real time. At the end of the eighties a large, comprehensive book appeared, in which a speech processing model was presented, discussed in great detail, and supported by a large number of empirical facts. This standard book, *Speaking* (1989) by Levelt, which still functions as a benchmark in the discipline, marks a definite turn in the approach to the study of speech production. A new era had begun.

7.2.2.1 *The picture-word interference paradigm*

A technique that soon became one of the most popular online research techniques for tapping into online speech production was the picture-word interference paradigm. In this paradigm, participants are shown a picture and asked to name it as fast as possible (speech production). However, a word is either written on the picture or presented auditorily, and participants are asked to ignore this word. The rationale is based on our knowledge that it is impossible for experienced readers or listeners to ignore a word. With respect to reading, the Stroop effect (Stroop 1935) has demonstrated this by showing that we cannot ignore a word when naming the colour of its letters: it is hard to say "red" to the word *green* printed in red letters. By manipulating the nature of the word that is presented with the picture, researchers have a probe to study the processing sequence during picture naming, i.e., word production.

In an influential study Schriefers, Meyer, and Levelt (1990) used this technique to demonstrate that the process of lexical access is a two-stage process: a first stage in which semantic information becomes available at a time when there is no access to phonological information yet and a second stage in which phonological information becomes available after the semantic information has been retrieved and the processor has no longer access to this previous representational level. When, for instance, the picture of a dog had to be named, presenting a semantically related distractor word like *cat* auditorily 150 ms before picture onset resulted in delayed naming times (interference) relative to a control condition (where e.g., the name *lip* was presented), whereas a phonologically related distractor like *fog* had no effect. In contrast, when presenting the two distractors and their controls 150 ms after picture onset, the phonologically related distractor delayed picture naming latencies whereas no effect was measured of the semantic distractor. So, when the distractor's meaning and the meaning of the visualized object reach the semantic system about simultaneously, as is the case when the word is presented shortly before picture onset, semantic interference results. When the phonological representations of both the distractor word and of the picture name reach the level of phonological representation simultaneously, as is the case when the word is presented shortly after picture onset, phonological interference results. These results clearly indicate that the process of lexical access is a two-step procedure: one during which so-called lemmas are retrieved, when only semantic and grammatical word information become available, and one during which so-called lexemes are retrieved, when only phonological word information becomes available.

Levelt, Schriefers, Vorberg, Meyer, Pechmann, & Havinga (1991) raised a somewhat different question with respect to the stages of semantic and phonological access during the process of lexical activation. The earlier observations that semantic and phonological interference occurs, suggest that word meanings and the phonological forms of words are both organized in semantic and phonological networks, respectively. When a speaker must name a picture, the meaning of the picture's name will cause spreading activation through the semantic network. A question that arises is whether the speaker immediately selects the semantic representation corresponding to the picture before any activation can propagate to the phonological representational level or not. Is it possible that semantic relatives are coactivated without concomitant activation of their phonological representations?

In their experiments the authors showed a picture and presented participants with an auditory word at different intervals after picture onset. These auditory words belonged to one of four types: (i) a name that was semantically related to the picture (e.g., *goat* for a picture of a sheep; to test whether the semantic representational level was still accessible at this stage), (ii) a name that was phonologically related to the name of this semantic relative (e.g., *goal* related to *goat;* to test whether coactivated semantic representations activated their phonological representations, which in turn coactivated their phonological neighbours), (iii) the name of the picture itself (*sheep*), and (iv) un unrelated name (*door*). The authors tested two types of relationship at the 'semantic' level: associative relatedness, which would cause coactivation due to the frequent co-occurrence of the words (*sheep* coactivating *wool*) and true semantic relatedness, in which case the two words belonged to the same semantic category (e.g., *sheep* coactivating *goat*). If coactivation at the semantic level were transmitted to the phonological level before the ultimate selection of the meaning of the picture name, the presentation of an auditory stimulus that is related to the name of either the associate (*wood* for *wool*) or the semantic relative (*goal* for *goat*) should considerably delay naming times, as the result of interference. This turned out not to be the case, which made the authors conclude that coactivation within the semantic network does not 'leak' into the layer of phonological representations. This suggests that the selection of a word meaning is already finished at the representational level of the lemmas, where its phonological form is not yet available, before the activation is fed forward to the next representational layer, where the words' phonological forms are stored.

It should be clear from the foregoing that the online techniques that are used in current-day experiments allow for insights at a more fine-grained level than the analysis of speech errors. At the same time, researchers adopting these techniques do not reject the validity of speech error data. On the contrary, one of their goals is to design processing models that cannot only account for the RT data but also for the speech error data.

7.2.2.2 *Implicit priming*

Instead of asking people to name pictures as a tool for studying the process of word production one can also ask them to produce a word that they have previously learnt as an associate of a probe word. For instance, when you learn the associative pair *bottle-lamp,* you will be able to say *lamp* upon hearing the prompt *bottle.* Obviously, using associative pairs to study the process of speech production does not serve the purpose of studying the associations themselves. Rather, by manipulating properties of the associations that participants have to learn one can achieve insight into the pieces of information that are relevant for word production. When all associative pairs have something in common and this shared property makes it easier to produce the associate, the researcher will be able to infer that this property plays a role in the course of word production.

This was the basic idea that inspired the initial work of Antje Meyer and led to the introduction of a new technique in the study of speech production. Levelt, Roelofs, and Meyer (1999) refer to it as the technique of implicit priming and point out that this technique has the advantage of imposing fewer constraints on the experimental materials. Indeed, the word that one wants the participants to produce no longer has to be picturable. Meyer addressed several theoretical issues regarding the processes underpinning speech production.

She (1990) wondered whether the phonological encoding of a word's syllables, one of the components in Levelt's model of speech production (Levelt 1989; see also Levelt et al. 1999) proceeds in a serial left-to-right order or in parallel. She presented people with lists of three paired associates, which they had to memorize until they could swiftly produce the second word when prompted with the first one. The so-called homogeneous condition contained three pairs of semantic associates in which each second word started with the same syllable (e.g., *single-<u>lo</u>ner, place-<u>lo</u>cal, fruit-<u>lo</u>tus;*

signal-beacon, priest-beadle, glass-beaker; captain-major, cards-maker, tree-maple). In the so-called heterogeneous condition participants studied the same materials but these were rearranged such that all first syllables in a triple differed (*single-loner, signal-beacon, captain-major; place-local, priest-beadle, cards-maker; fruit-lotus, glass-beaker, tree-maple*). Meyer found that response times were significantly faster in the homogeneous condition than in the heterogeneous one. However, in bisyllabic words, she found only facilitation when the common syllable across response words was the first one, not when it was the second one (*murder, ponder, boulder*). Moreover, she found that in trisyllabic words, a shared second syllable did facilitate response speed, but only when the first syllable was shared as well. She concluded that participants who know that the first (or first two) syllables of the response are always the same in the set of studied words can start preparing the process of phonological word encoding and complete it when they receive the prompt. However, they cannot initiate this process when they do not know the identity of the first syllable. Hence, she showed that words are phonologically encoded in a strictly left-to-right order.

Meyer (1991) used the same technique to focus on the syllable constituents, the onset and the rhyme, the onset being the consonant(s) preceding the vowel and the rhyme being the vowel and all subsequent consonants (if any). For monosyllabic words she found an advantage in the homogeneous condition when the three responses shared their onset but not when they shared their rhyme. This outcome also obtained for bisyllabic words. Moreover, for the latter word type she found larger facilitation in the homogeneous condition the more phonemes of the first syllable were shared by the response words. There was facilitation with shared onsets, more so when both the onset and the vowel were shared, and the largest facilitation when the whole syllable was shared. Meyer concluded that the phonological encoding of the syllable is also an incremental process, the onset being encoded before the rhyme.

With the same technique Roelofs and Meyer (1998) showed that the fully phonologically encoded word is a representation in which the syllabified phoneme sequence is associated with a metrical frame that specifies the stress pattern across the word's syllables. This conclusion was based on two observations: (i) the homogeneous condition facilitated responses to the probe words when all response words shared the word-initial segments but also had the same metrical frame, i.e., the same number of syllables with the same stress pattern, independently of whether they had the same number of vowels and consonants, (ii) the homogeneous condition did not facilitate responses when the responses shared their metrical pattern but did not have the same word-initial segments. In order to have a headstart and being able to start preparing the response one needs both segmental and suprasegmental information.

The implicit priming technique has thus shown that the process of phonological encoding in speech production is a highly incremental process. This incrementality was also demonstrated by Wheeldon and Levelt (1995) in experiments where participants had to monitor their internal speech production.

7.2.2.3 *Producing multiple words*

Whereas much reaction time research on speech production has focused on single word production, studies from the mid-nineties of the previous century started to focus on the processes that are involved in the production of multiple words.

In Meyer's study (1996) participants were shown two pictures next to each other on a computer monitor. In one type of experiment they had to name the pictures in a phrase of the type "the N_1 and the N_2" (e.g., *de boom en de vlag* – the tree and the flag), in another type they had to make a short sentence (e.g., *de boom staat naast de vlag* – the flag is next to the tree). The purpose of the study was to find out at which processing level (semantic or phonological) the production process had arrived for each word at the moment of response initiation. To that end, two experiments (one for each of the above-mentioned response types) made use of semantic distractors for either the first picture (*struik* for *boom* – bush for tree) or the second picture (*wapen* for *vlag* – weapon for flag), which were presented at picture onset or 150 ms before it. In two other experiments the auditory distractors were phonologically related the first picture (*boor* for *boom* – drill for tree) or the second picture (*vlas* for *vlag* – flax for flag).

There was no difference between the two response types (conjunction vs short sentences), for neither distractor type. Semantic distractors for both nouns delayed responses, whereas phonological distractors facilitated responses only for the first picture name. Meyer concluded that at the time participants began to speak they had retrieved the lemma for both pictures, which contains the semantic and grammatical information, but only the phonological form for the first picture. Thus she demonstrated that one production process was still underway while the other one was finished.

Meyer, Sleiderink, and Levelt (1998) also studied the naming of pairs of pictures. They wanted to know whether participants' viewing times for pictured objects could shed light on the planning stages involved in speech production. On each trial participants saw a pair of objects whose names were either both HF or LF names. Both their naming latencies and their viewing times on the left object were measured (objects were named from left to right). They found a significant frequency effect on both naming latencies and viewing times. However, when participants did not have to name the objects but only to discriminate them from non-existing objects, the frequency effect on viewing times disappeared. The authors conclude that if, as is often assumed, frequency determines the accessibility of the word's phonological form, the finding that frequency affected viewing times on the left object only in a naming task indicates that the participants' eyes do not leave this object before they have phonologically encoded it. Meyer's (1996) study mentioned in the previous paragraph further suggests that before speech initiation participants will already process the second object till they have retrieved its semantic properties (lemma level) but not its phonological form.

7.2.2.4 *Models of speech production*

The big divide between two types of speech production models is the debate about their degree of interactivity. Should an adequate model of speech production be considered as a sequential, feedforward model, in which later processing stages have no impact on previous ones? Or should it be considered as a highly interactive model in which later stages feed back their information to previous stages, thus helping these earlier processes when they are 'in trouble' by feeding them the information assembled at later processing stages?

Ten years ago Levelt (1999) wrote a paper in which he stated that the best-known interactive model, the one developed by Gary Dell (1986), and the best-known feedforward model, the one developed by himself and collaborators, stem from two different research traditions – speech error research and chronometric speech production studies, respectively. He emphasized the commonalities between the models rather than stressing their differences and made the optimistic claim that "These research traditions have begun to merge in recent years, leading to highly constructive experimentation. Currently, they are like two similar knives honing each other. A single pair of scissors is in the making." (p. 223).

I will not enter into this debate here, because it could form the topic of a separate chapter on speech production. However, it is worth emphasizing that Dell's interactive model indeed originated in the tradition of speech errors and contains properties that are especially intended to account for a particulary frequent type of error: so-called mixed errors, which evidence that neighbouring representations have been activated at both the semantic and phonological level of word representation. For instance, a speech error like *rat* when the intended word is *cat,* suggests that both a related semantic and phonological representation have become active. The shared phonemes */a/* and */t/* with the target word *cat* and the feedback of the activity in phonological representations to the semantic level (and back again) accounts for the emergence of a mixed speech error.

The model developed by Levelt (1989) and layed out in his book *Speaking: From Intention to Articulation,* has its roots in chronometric experiments and, as mentioned before, consciously so. The percentage of speech errors is so low (1%–2%) that the starting-point of this model is non-erroneous language use. Using an analogy one could say that the best way to study how a device works (e.g., a radio, a car) is by studying its normal function, not by studying its defective behaviour. Note that this does not discount my earlier statement that the structure of a device determines its function and that by studying faulty function one can derive restrictions on the way it is internally structured. And indeed, Levelt and colleagues readily admit that their model, too, (which has been implemented in the computer model WEAVER by Ardi Roelofs 1997) must be able to account for the patterns observed in speech error corpora.

Some researchers still adhere to highly interactive processing models whereas others try to limit interactivity as much as possible. Still others make an attempt to unite the two, claiming that both discrete and interactive processing are probably involved but that it remains to be seen which stages interact and which behave as modules (see, for instance, Rapp & Goldrick 2000).

8. Conclusion

In this chapter I have made an attempt to achieve two goals. My first goal was to characterize psycholinguistics as a separate discipline, with its own set of goals, methodologies, and techniques. My second goal was an attempt to sketch some of the major topics in past and (especially) current psycholinguistic research on all four language skills: reading and writing, speech perception and speech production. Thus the two dimensions behind our language skills have been covered: the mental processes and representations involved in oral and written language (modality) and the mental processes and representations involved during language perception and production (language user's activity). As mentioned before, this review does not pretend to be complete. For instance, it largely focuses on lexical processing. Nonetheless, by attempting to achieve the above goals and making the discussion as concrete as possible by describing actual experiments, I hope readers have achieved a good view on what psycholinguistics is about.

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The multilingual lexicon

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Modern media, like e-mail and internet, allow us to communicate with language users from all over the world after just one button press. As was already prophecized by the Canadian linguist Marshall McLuhan in 1962, our world is becoming more and more like a 'global village' in which it is not self-evident that a person speaks only one language. For the exchange of cultural and scientific knowledge, and for doing business abroad, people are pressed to speak more than one language and therefore become multilingual. We are witnessing an increase in the interest for multilingualism, which seems justified because there are probably more multilinguals in the world as a whole than monolinguals. Note there are about 200 independent states in the world and about 6800 living languages. In other words, there are more than 30 times as many languages than countries. If more than one language is spoken in a country, many inhabitants of that country will be multilingual themselves, because otherwise a Babylonian confusion of tongues would rule.

In the current 27 member states of the European Union, 23 official languages are spoken by about 480 million people. A multilingual education is seen as rather important in the Union, and it has officially included Multilingualism in the portfolio of the Commissioner for Education and Culture (at present Leonard Urban). A survey of the European Commission conducted at the end of 2005 showed that about half of all Europeans is capable at present of having a conversation in at least one language next to their mother tongue or L1 (Special Eurobarometer 243, 2006). For about one third of the EU population, the second language or L2 is English, followed by German and French at 14%, and Russian and Spanish at 6%. Nearly 8 out of 10 students in the Union are able nowadays to use at least one foreign tongue. In several European countries, over 90% of the inhabitants master, in addition to their mother tongue, one or several foreign languages. For instance, the Dutch are in fact mostly multilinguals, because they speak German and/or French next to Dutch and English. 'Speaking a foreign language' here indicates that language users feel they can have a simple conversation in a foreign language, or at least can express themselves as needed. This rather pragmatic description of multilingualism holds for the majority of multilinguals in the world.

1. The multilingual processing system

At the basis of multilingual communication lies the capacity of the individual to comprehend and produce multiple languages. One important component of the multilingual's cognitive processing system is the *word recognition system*. This system incorporates a large database of words from various languages, called the multilingual lexicon. Many questions have been raised with respect to multilingualism in general and multilingual word recognition in particular. Are the word forms, meanings, and grammars of different languages stored separately or in an integrated fashion? Do the languages one speaks affect each other? Is there an advantage or disadvantage to speaking several languages? How are languages stored in our brains? What happens in my mind if I switch to a different language? How do we process words from different languages that are similar in form but not meaning, like the Dutch word SMART (a 'false friend' to English SMART) that refers to 'grief' rather than intelligence? And what about a Dutch word like POLITIE that is similar in both form and meaning to the English word POLICE (making it a so-called 'cognate')?

Such questions are not easy to answer. Even speaking, writing, reading, and understanding a single language is a remarkable accomplishment. Language users normally understand 3–5 words per second, while they know perhaps 50,000 words in their mother tongue. This implies that within a third of a second, a correct word selection can be made out of a vast mental dictionary. Because multilinguals probably know several tens of thousands of additional words, this makes their performance even more special.

A complete theoretical account of language processing in multilinguals must go beyond a study of the structures and processes of various native languages on their own. Otherwise, one would disregard possible interactions of the native language with the acquired foreign languages. It might be possible (and, in fact, even likely) that, perhaps even unnoticed by us, the processing in one of our languages is affected by our knowledge of another language. In other words, we need a psychological account of the processing of multiple languages and their interactions. In the long run, such a psycholinguistics might help us to improve the teaching methods for foreign languages, furthering European integration (in accordance with the goals of the European Commission). Possibly, such teaching methods must be adapted to the age at which a foreign language is acquired and to the relationship between the new language and the native language. It is also possible that research helps us to better understand what happens after the loss of one or more languages following brain damage, or when someone has lived abroad for many years. However, scientific research is not always focussed on a straightforward accomplishment of applicable results. Many scientists are driven by their curiosity concerning the nature of our mental world.

2. Multilingualism and word recognition

The lion's share of psycholinguistic research, both monolingually and multilingually, is concerned with words presented in isolation. Because words are the building blocks of sentences, this may be less strange than it seems; it underlines the importance of the word in a language. By now, we know enough about the process of word recognition to simulate it in computer models. A large part of the research in our lab has taken place in the framework of the *Bilingual Interactive Activation Plus model (BIA+ model)*, an implemented model for bilingual word recognition (Dijkstra & Van Heuven, 1998, 2002; Van Heuven, Dijkstra, & Grainger, 1998). This model was developed on the basis of an existing model for word recognition within a language. The model (see Figure 1) assumes that words are recognized in a series of steps. Suppose one reads the word WORK. The curved and straight lines on paper first activate certain letter representations in memory. These letters then activate possible words, like CORK, FORK, WORN, and WORK. Such similar words that differ in only one letter position from the presented word are called 'neighbors'. Through a gradual process of elimination, the neighbors are excluded as potential targets and finally only the presented word, WORK, remains active. Complex interactions between letters and words make the activation process very difficult to predict without actual simulation. In addition, the task that must be performed (e.g., name the word, or decide whether a letter string is a word at all) is important in determining the ultimate response of the reader.

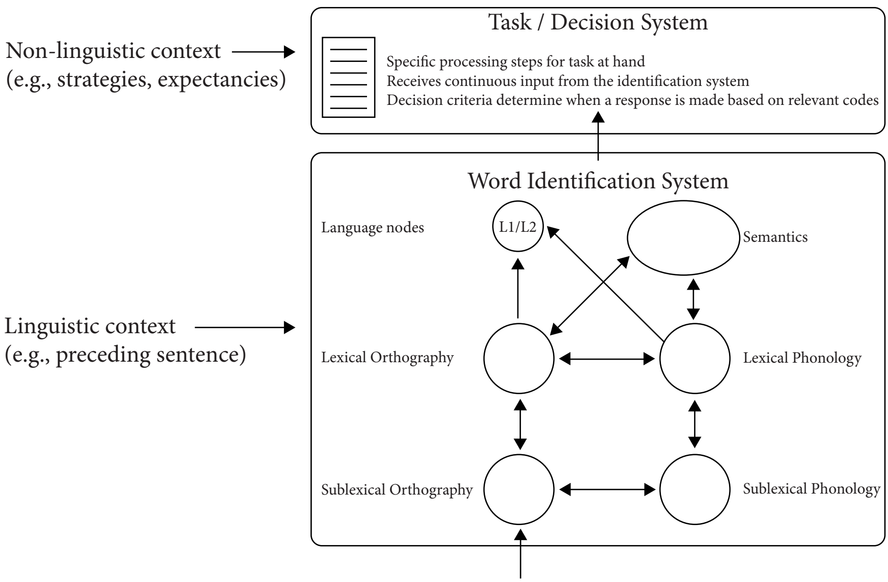

Figure 1. The Bilingual Interactive Activation + (BIA+) model for bilingual word recognition
In this model, aspects of the non-linguistic context (such as participant instruction) may affect how a multilingual task is performed. Linguistic context (such as sentence context) may directly affect the activity of word representations during recognition.

A central issue on which the model takes a stand is how, during reading, words from the various languages a person knows affect each other's recognition. The model assumes that words from different languages are stored in a mixed database in our memory. This database is therefore called an 'integrated lexicon'. The model further assumes that during reading, many words from different languages are considered – activated – namely, all those words that are similar to the presented string of letters. In other words, when the English word WORK is presented, a Dutch-English bilingual will also activate Dutch word possibilities like VORK (meaning 'fork'), WERK (meaning 'work'), and WORP (meaning 'throw'). The recognition process is therefore a process of 'language nonselective lexical access'. To which language a word belongs, usually becomes known in the system only after the presented word has been identified.

The two major assumptions of the model, that the multilingual lexicon is integrated and is accessed in a language independent fashion, are based upon a host of studies done in the last 20 years, many of which are discussed later in this paper. Interestingly, this now prominent theoretical view is the result of a complete theoretical turn about. Until about 1990 or so, many researchers believed that the word recognition process was language dependent and that word form representations were accessed in a language-specific way (e.g., Gerard & Scarborough, 1989; Kroll & Stewart, 1994; Smith, 1997; see discussion by Paradis, 1981). (Meaning representations, in contrast, might be shared by different languages due to their non-linguistic nature.) In line with this viewpoint, there were a number of early studies that failed to find cross-linguistic effects on bilingual word recognition (Caramazza & Brones, 1979; Macnamara & Kushnir, 1971; Soares & Grosjean, 1984). For instance, Gerard and Scarborough (1989) failed to find effects of cross-linguistic word form similarity on bilingual processing. In an English lexical decision task, English monolinguals and Spanish-English bilinguals took about as long to decide that ACTUAL (a cognate), RED (a false friend, meaning 'net' in Spanish), and CHAIR (a purely English control word) are English words, suggesting that there was no effect of the native language Spanish on word processing in the second language, English. In addition, word latencies were primarily dependent on the frequency of usage in the target language, not the other language. Finally, no significant latency differences were found between bilinguals and monolinguals, suggesting that they were all effectively operating in a language selective manner. In sum, this early study suggested that lexical access in bilingual word recognition was restricted to only one language.

However, later studies showed that the observed null-effects were only replicable under particular conditions of task demands and stimulus list composition (e.g., Dijkstra, Van Jaarsveld, & Ten Brinke, 1998; De Groot, Delmaar, & Lupker, 2000; Von Studnitz and Green (2002). In many other experimental situations, cross-linguistic effects were observed (either facilitatory or inhibitory in nature). Thus, it gradually became clear that lexical access to the lexicon in its earliest stages is not limited to one language (for reviews, see Dijkstra, 2005, 2007).

It has been more difficult, however, to convincingly demonstrate that the multilingual lexicon is not only accessed in a language nonselective way, but is also structurally integrated.

Perhaps the most convincing evidence as yet has been collected by Van Heuven, Dijkstra, and Grainger (1998), who showed that the number of word neighbors from different languages influenced the processing of form-similar but non-identical target words. Van Heuven et al. manipulated the number of orthographic neighbors of the target words in the first and second language of Dutch-English bilinguals in a series of progressive demasking and lexical decision experiments. Increasing the number of Dutch orthographic neighbors systematically slowed the response times (RTs) to English target words. Within the target language itself, an increase in number of neighbors consistently produced inhibitory effects for Dutch target words and facilitatory effects for English target words. Monolingual English readers also showed facilitation effects dependent on the number of English neighbors, but no effects of Dutch neighborhood density. It is hard to see how word candidates of different languages would affect target processing if the bilingual word form lexicon is not integrated.

3. Multilingualism and special words: Cognates

Many studies have used 'special' words such as cognates and false friends to investigate lexical presentation and access in bilinguals. Most words in a language are unique for that language; such words lend themselves to the manipulation of within- and between-language neighborhood density, as described in the previous section. However, there are also words in a new language that have (almost) the same form and meaning as in the native language. Such words are called *cognates*. We often encounter them in our first lessons in a foreign language, because they are so easy to understand and learn. For instance, the meaning of the Dutch word TOMAAT will be directly clear to a speaker of English, because it is so similar to the English word TOMATO (in contrast to the Italian translation equivalent POMODORO). Even words from very different languages may be similar, such as the English word GUITAR and its Japanese equivalent, which (though written very differently) sounds like /GI.TA.A/. Technically said, cognates are translation equivalents that are similar in form; they have more or less the same meaning and also more or less the same (written and/or spoken) form.

In recent years, an important research question has been how cognates are stored in the memory of a bilingual and how they should be incorporated in a computer model such as the BIA+ model discussed above. Research in many laboratories all over the world has led to the following findings and conclusions.

Cognates are processed more quickly and with fewer errors during reading, listening, and speaking than words existing in only one language (e.g., reading: Cristoffanini, Kirsner, & Milech, 1986; De Groot & Nas, 1991; Dijkstra, Van Jaarsveld, & Ten Brinke, 1998; Dufour & Kroll, 1995; Friel & Kennison, 2001; Kroll & Stewart, 1994; Sanchez-Casas, Davis, & Garcia-Albea, 1992; listening: Caramazza & Brones, 1979; Marian & Spivey, 2003; speaking: Costa, Caramazza, & Sebastian-Galles, 2000; Costa, Santesteban, & Cano, 2005). Brain waves for cognates are also different from those for matched control words (e.g., in terms of the N400 component; De Bleser et al. 2003; Dijkstra, Van Hell, & Brenders, in preparation). Faster RTs to cognates have also been observed in bilinguals using different scripts (Gollan, Forster, & Frost, 1997; Kim & Davis, 2003).

The processing advantage for cognates is called the *cognate facilitation effect*. It is usually larger in a second language than in a first language (Kroll, Dijkstra, Janssen, & Schriefers, 2000), although it also occurs in the mother tongue if the bilingual is sufficiently proficient in the foreign language in question (Van Hell & Dijkstra, 2002). Stronger facilitation effects can arise if the cognates in question exist in three languages rather than in two, like the word ECHO that exists in English, German, and Dutch (Lemhöfer, Dijkstra, & Michel, 2004). Recent evidence indicates that cognate effects can be modulated by sentence context (Schwartz & Kroll, 2006; Van Hell & De Groot, 2008; see below).

The cognate effect must be a consequence of the combination of overlap in meaning (semantics), spelling (orthography), and/or pronunciation (phonology) across languages. All three characteristics contribute to the effect (Dijkstra, Grainger, & Van Heuven, 1999). For instance, Dijkstra, Brummelhuis, and Baayen (under revision) found that the cognate effect became larger during an English lexical decision task performed by Dutch-English bilinguals when the cross-lingual form overlap of the cognates became larger (with constant meaning overlap), for instance going from COLOUR (Dutch: KLEUR) to WHEEL (Dutch: WIEL), to ALARM (Dutch: ALARM). In this study, a separate group of participants rated the degree of form overlap on a 7-point scale.

The cognate effect also depends on the task at hand and can even result in an interference effect, for instance in a language decision task in which participants must determine if a word belongs to one language or another (Lavaur & Font, 1998). In other words, form overlap helps if one does not have to distinguish the two readings of the cognate, but it hinders if one must discern them.

These results have consequences for the way in which cognates are supposedly stored in our mental lexicon. The existence of a cognate facilitation effect suggests that cognates do not have a completely separate and independent representation in the two languages. But does this imply that there is a common representation? It has been proposed that cognates such as ACCOMMODATION (English) and ACCOMMODATIE (Dutch) have a shared morphemic representation (Cristoffanini et al. 1986; Lalor & Kirsner, 2000; Sanchez-Casas & Garcia-Albea, 2005). However, it does not seem to be likely that this can hold for all cognates. Note that words like TOMATO and TOMAAT consist of only one morpheme, which has its own orthographic form and also a different plural form in each language (TOMATOES vs. TOMATEN) in the different languages. An alternative proposal for the representation of non-identical cognates is depicted in Figure 2 (also see Voga & Grainger, 2007). It consists of a separate but overlapping orthographic representation linked to an also overlapping or shared semantic representation. According to this view, the cognate facilitation effect in many tasks arises because both word forms become active during the presentation of one of them and then converge on the common meaning representation. However, in language decision, the two overlapping representations are linked to different responses (e.g., TOMATO to English, TOMAAT to Dutch). As a consequence, a cognate inhibition effect arises.

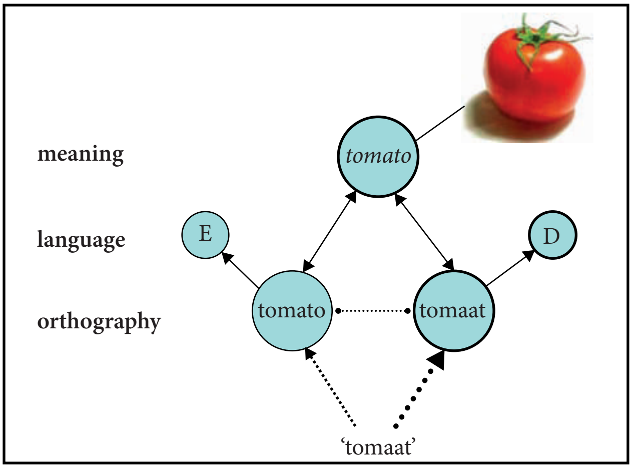

Figure 2. Representation of non-identical cognates

4. Multilingualism and special words: False friends

A second type of 'special' words that are often used in research are so-called 'false friends'. It turns out that not all similar word forms from various languages have the same meaning. 'False friends' are alike in their written form and/or pronunciation for different languages, but they have quite a different meaning. An example is the word form LIST, which exists in both Dutch and English. In the movie 'Schindler's list', the English meaning of the word is important, not the Dutch meaning, which refers to a 'trick' (the Dutch expression 'Schindlers list' would refer to a trick pulled by Schindler). Just as in the case of cognates, it is important to find out how false friends are represented in the mental lexicon of the multilingual. A proper understanding of their representation will also clarify how different languages may mutually affect each other.

We could provide a first test of whether false friends affect each other by a little 'thought experiment'. Consider the following list of pop groups and hit songs.

Pop group	*Song*
Cream	White room
Iggy Pop	Little doll
Pink	Fingers
Sting	Angel eyes
George Baker	Drink, drink

The question is whether Dutch-English bilinguals would always notice the special link between the names of the pop groups and the songs. This, in my experience, is usually not the case. The bilinguals tend to overlook, for instance, that the English word CREAM refers to what in Dutch is called 'witte room'. Apparently, the Dutch word ROOM, a false friend of the English ROOM, does not 'automatically' come to mind during the reading of the name of the English pop group.[1] Many people who are not language scientists will consider the bilingual's unawareness of the link between the English and Dutch items as trivial. They may, for instance, reason as follows: 'If one knows several languages and wishes to speak to someone else, then one must choose a particular language. So if one chooses an English sentence or reads the English title of a pop song, consisting of several English words, then English is chosen as the language of the sentence. Subsequently reading ROOM does not remind one of the Dutch word. And, by the way, if one reads an English sentence or book, then Dutch is not relevant anyway.' This sort of reasoning is largely based on introspection (looking into one's own mind). Unfortunately, scientists have shown that introspection is a very unreliable research tool. The question of whether during reading of the English word ROOM, the Dutch word ROOM also becomes active, must therefore be tested by means of scientifically sound experiments. Fascinatingly, experimental studies have shown that the intuition that only one reading of the false friends becomes active, is wrong! Experimental research has led to the following insights.

When Dutch-English bilinguals read or listen to the English (L2) variant of Dutch-English false friends, the words in both languages become active. This conclusion is based on the finding that in many different tasks, for instance, lexical decision and word naming, the reaction times for false friends are often longer than for control words (Smits, Martensen, Dijkstra, & Sandra, 2006; Von Studnitz & Green, 2002). False friends apparently suffer from an interference effect dependent on the relative frequency of the false friends in the two languages. For instance, a relatively low-frequency English word like RAMP is most strongly interfered with by a high-frequency Dutch counterpart like RAMP (meaning 'disaster'). It has been shown that this slowing-down effect can be reduced and even eliminated by excluding pure Dutch words from the stimulus list. And if the task is changed into

1. To clarify the other examples: A Dutch POP is a DOLL, a Dutch PINK refers to a little finger, a STING is delivered by an ANGEL (Dutch for 'stinger'), and a Dutch BEKER, pronounced as BAKER, is a BEAKER.

'is the presented word a word in one language or another?', then the false friends are even processed faster than control words (Dijkstra, Van Jaarsveld, & Ten Brinke, 1998).

In sum, in contradiction with our intuition, there is an effect of the Dutch reading of a false friend on the processing of its English counterpart. The ultimate response to false friends depends, however, strongly on the list in which they occur and the task that must be executed. It has been shown (Schulpen, 2003) that the observed results can be generalized to different age groups and hold for multilinguals between 15 and 45 years of age. Thus, although the speed and accuracy of responding to false friends increases in bilinguals with increasing L2 proficiency, the word identification and task/decision systems appear to function in the same fashion across a wide age range.

Another effect on item recognition is exerted by the number of words that is morphologically related to the false friends in each language. Take, again, the word ROOM. In Dutch, words exist that are morphologically related, like SLAGROOM ('whipped cream') and ROOMPOT ('pot of cream'). In English, there are words like WORK ROOM and ROOM SERVICE. The more morphologically related words exist in a certain language, the faster the processing is of the false friend in that language. However, if there are more related words in the other language, then processing is slowed down instead (Dijkstra et al., 2004).

Recently, Akker and Dijkstra (in preparation) have shown that upon auditory presentation of a Dutch word like PEES ('tendon'), the English word PACE that sounds more or less the same, is also activated in Dutch-English bilinguals. This is an exciting finding, because it shows that multilinguals in their processing of a spoken mother tongue can be affected, even without knowing it, by a foreign language, if they are proficient enough in that language. Therefore, the effect across languages is not restricted to cognates, for which both form and meaning overlap exists (Van Hell & Dijkstra, 2002).

Cross-linguistic effects for false friends have also been shown in electrophysiological and neuroimaging studies. For instance, in a combined EEG (ERP) and reaction time (RT) study, Kerkhofs, Dijkstra, Chwilla, and de Bruijn (2006) found that the response to a Dutch-English false friend, presented following an unrelated word, is affected by the frequency of the Dutch reading of that false friend. When the frequency of the Dutch reading was higher, there was a more negative-going N400 wave, indicating stronger interference effects. At the same time, reaction times were slower. Furthermore, in an fMRI study, Van Heuven, Schriefers, Dijkstra, and Hagoort (2008) found that the conflict between the two false friends could also be localized in the brain, in particular in the frontal areas that are associated with the monitoring and resolution of conflicts during task performance. There also was a clear difference depending on the task that the bilingual participant was performing. Much stronger competition effects arose when the task required the participant to respond only to one reading of the false friend (an English lexical decision task, in which only English words received a 'yes' response) than when either reading was correct (a generalized lexical decision task, in which both English and Dutch words were linked to 'yes, it is a word' responses).

On the basis of these and other studies, the representation in Figure 3 is proposed for false friends. As will be seen in comparison to Figure 2, this representation is directly in line with that for cognates. A Dutch-English word like RUG has two representations, one for English and one for Dutch. Both representations are characterized by their own frequency of usage and both have their own representation for meaning and pronunciation.

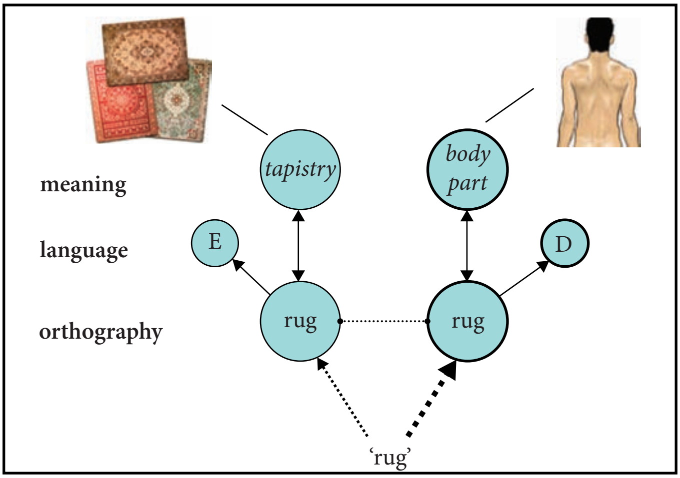

Figure 3. Representation of false friends

The various studies on isolated words, including neighbor words, cognates, and false friends, provide abundant evidence in support of an integrated multilingual lexicon and a language-independent access process to this lexicon, of which the effects are modified by task-dependent and stimulus-list dependent decision mechanisms. In other words, these studies reveal to us the fundamentally language-nonselective nature of the bilingual word recognition system. However, the question is whether this nonselectivity will still play a role at the more natural level of sentence processing. We will consider this issue in the next section.

5. Multilingualism and sentence processing

Conversations between language users consist for a major part of sentential utterances. Although a conversation may last for minutes, the production and understanding of a single utterance takes only a few seconds. Psycholinguists are interested in the complex, interactive processes that affect the recognition of words in sentence processing. For instance, suppose one reads the sentence '*She took a bite of the fresh green apple*'. To understand this sentence, the word forms on paper need to be recognized and put into a syntactic structure of the sentence as a whole. At the same time, the meanings of the individual words must be grasped, they must be related to one another, and they must be linked to world knowledge, for instance, that fruit can be consumed in small quantities, obtained by biting it. By the time one reads the word 'apple', the earlier words in the sentence have already been processed to a large extent. Probably, a syntactic structure and a meaning structure for the sentence have already been constructed by the time that the word 'apple' is read. This word is then integrated within these structures. Now suppose that we replace the English word 'apple' in this sentence by the Dutch word 'appel' (meaning 'apple'), leading to the sentence '*She took a bite of the fresh green* appel'. How would the reading of this sentence by an English-Dutch bilingual be affected by this change? On the one hand, one might expect a much longer reading time when 'appel' appears, because of the mismatch between expectations based on the earlier sentence context and the actual word on paper. On the other hand, the target words 'apple' and 'appel' are very similar in writing, pronunciation, and meaning; they are cognates. Relative to words that exist in only one language (such as 'citroen', meaning '*lemon*'), the word 'appel' might therefore be recognized more quickly.

6. The BIA+ model and sentence processing

As we have seen above, according to the Bilingual Interactive Activation + (BIA+) model for bilingual word recognition (Dijkstra & Van Heuven, 2002), processing of a cognate word like '*apple*' or '*appel*' in the early stages will lead to co-activation of its other-language orthographic reading, so '*apple*' will also activate '*appel*' and vice versa. Next, both '*apple*' and '*appel*' activate a (largely) shared semantic representation (see Figure 2). The resulting resonance between orthographic and semantic codes will lead to an increased total activation in the bilingual lexicon for '*apple*' relative to an otherwise comparable word without form overlap (e.g., '*bike*' – '*fiets*'). The lexical decision that '*apple*' is a word will therefore be easier and faster to make than such a decision for a control word (the cognate facilitation effect, see above).

The BIA+ model further assumes that the recognition of words can be affected by the syntactic and semantic aspects of the sentence they occur in. The underlying bilingual mechanism that has been proposed is similar to the *feature restriction* hypothesis by Schwanenflugel and colleagues (Schwanenflugel, 1991; Schwanenflugel & LaCount, 1988; Schwanenflugel & Shoben, 1985) and Kellas, Paul, Martin, and Simpson (1991) in the monolingual literature. According to this view, readers use sentence context to generate semantic/pragmatic, syntactic, and lexical feature restrictions to facilitate the processing of upcoming words. These feature restrictions are compared to those of the upcoming words, allowing an easier or more difficult integration of the items in the various sentence structures. A critical prediction of this account is that plausible but unexpected words in high constraint sentences are slowed down, whereas a broad range of words might be facilitated in a sentence context providing only a low semantic constraint. Indeed, Schwanenflugel and La Count (1988) observed facilitation only for expected sentence completions following high constraint sentences, whereas after low constraint sentences, lexical decision latencies were facilitated for both expected and unexpected target words.

Because the BIA+ model assumes there is language nonselective access to semantic, syntactic, and lexical information sources, it predicts that sentential context will constrain the number of activated lexical competitors from both target and non-target languages. However, in the bilingual situation, at least three additional factors come into play: the language of the preceding sentence, the language of the target word to be recognized, and the cognate status of the target item. This would appear to be a complicating factor in bilingual research into the relative contribution of various factors during the integration of words in a sentence context. Fortunately, the effect of certain factors can be kept constant across experimental conditions. Notice, for instance, that following a sentence like '*She took a bite of the fresh green*', the sentence-based syntactic, semantic, and lexical expectations will stay the same for different types of added target nouns. This makes it particularly interesting to investigate the effects of preceding sentence context on translation equivalents with and without form overlap, such as non-identical cognates and matched noncognates.

7. Empirical studies on bilingual sentence processing

Empirical research investigating how bilingual word recognition is affected by sentence context has been initiated only recently. Both behavioral and event-related potential studies have been conducted, involving different types of special target words, such as interlingual homographs and cognates.

One early bilingual sentence study that appears to be in line with the feature restriction hypothesis was done by Altarriba, Kroll, Sholl, and Rayner (1996). These authors examined semantic and lexical form effects of a preceding sentence context on bilingual word recognition in two experiments. In their first experiment, they monitored the eye movements of Spanish-English bilinguals who were reading English (L2) sentences that contained either an English (L2) or a Spanish (L1) target word. Sentences provided either high or low semantic constraints on the target words. An example sentence of the high constraint and Spanish target condition is '*He wanted to deposit all his dinero at the credit union*', where *dinero* is Spanish for "money'. The experiment showed that the frequency of the target word and the degree of sentence constraint interacted with respect to the first fixation duration for Spanish targets, but not for English targets. Specifically, when the Spanish target words were of high frequency and appeared in highly constraining sentences, an interference effect arose. This finding suggests that the sentence generated both semantic and lexical features as constraints for the upcoming target words. A high-frequency Spanish word matched the generated set of semantic features, but not the expected lexical features, when it appeared following an English sentence context (Altarriba et al., p. 483).

The same pattern of results was observed in a second experiment, in which the sentences were presented word by word using the Rapid Serial Visual Presentation (RSVP) technique and participants named the capitalized target word in each sentence. In sum, the findings of this study indicate that target word recognition can be affected by a preceding bilingual sentence context.

In a more recent study, Elston-Güttler, Gunter, and Kotz (2005) examined how the activation of the two readings of false friends (interlingual homographs) was affected by the local sentence context and by the more global discourse context. They asked German-English bilinguals to perform a semantic priming task, in which German-English homographs were presented as primes at the end of English sentences. These were then followed by English targets for lexical decision. For example, the sentence '*Joan used scissors to remove the*' was followed by the test word TAG (a German-English interlingual homograph, which means 'DAY' in English) or a control word (e.g., LABEL). Next, a target word (e.g., DAY) was presented on which an English lexical decision was made. The more global language context was manipulated by playing a 20-min silent movie at the beginning of the experiment, accompanied by a narrative in either L1 (German) or L2 (English). Both behavioral and EEG (ERP) data revealed semantic priming effects only in the first part of the experiment after the bilinguals had seen the German movie. This finding suggests that (1) the local English sentence context apparently prevented the activation of the non-target reading of an interlingual homograph (e.g., the German reading of TAG), and (2) the more global context also affected the priming effect, reflected in a modulation of the N200 and N400 components in the EEG (the latter is considered to be a marker for ease of semantic integration) and in the response times for the first part of the first block just after the German movie was shown. Elston-Güttler et al. (2005) argued that bilinguals who saw the German movie had to zoom in to their L2 (English) by gradually raising decision criteria in order to diminish non-target language effects of L1 (German) on the target language L2 (English)[2]. In all, the results of this study are compatible with the more general view that sentence context can affect the activation of representations in the bilingual word identification system (Dijkstra & van Heuven, 2002).

More specifically, recent studies suggest that semantically constraining sentences can reduce or even eliminate the effects of a non-target language on item processing, while such effects may remain in low-constraint and neutral sentence context (Schwartz & Kroll, 2006; Duyck, van Assche, Drieghe, & Hartsuiker, 2007; van Hell & de Groot, 2008). Schwartz and Kroll (2006) asked Spanish-English bilinguals to name words that were inserted in sentences that were highly or less constraining from a semantic perspective. Using an RSVP paradigm, they presented cognates and false friends in bilingual sentences that were semantically more or less constraining. An example of a high-constraint sentence is '*The composer sat at the*

2. In a later study, Paulmann, Elston-Güttler, Gunter, and Kotz, 2006, did not observe an effect of global language context for the same task and stimulus words presented as isolated prime-target pairs.

bench and began to play the piano *as the lights dimmed.'* The word *piano* appeared in red and had to be named by as quickly and accurately as possible. Effects of the non-target language reading mostly persisted for cognates and false friends in a sentence context. For example, cognate facilitation was still found in low-constraint sentences. However, the cross-language effects in high-constraint sentences were found to depend on the L2 comprehension performance of the bilinguals: They disappeared for good comprehenders.

Duyck et al. (2007) had Dutch-English bilinguals perform an English lexical decision task on form-identical and non-identical cognates that were presented as final words in low-constraint sentences. Cognate facilitation effects were found relative to control words for both form-identical and non-identical cognates. The obtained effects were at least as large as the effects for the same items observed in isolation. Next, an eye-tracking experiment, in which the sentences with their cognates and a continuation phrase were represented as wholes on a computer screen, replicated the cognate effects for identical cognates, but not for non-identical cognates. The observed effects already emerged during the first fixation on the cognate targets. The authors conclude that lexical access in bilinguals may be language independent (nonselective) both in isolated word recognition and in sentence-embedded word recognition. Sentence context may interact with lexical variables of the words to be recognized, such as cross-linguistic orthographic overlap, and influence the cross-linguistic spreading of activation.

Interestingly, in a bilingual sentence study by Van Hell and De Groot (2008), results were obtained that appear similar in some, but not all, respects to the studies just reported. Dutch-English bilinguals performed an English lexical decision task or translated words in forward (Dutch to English) or backward (English to Dutch) direction. After reading a low constraint sentence context in the same language, cognate effects remained in all three tasks, although they were sometimes diminished in size relative to presentation in isolation. However, in high-constraint sentence context, the cognate effects disappeared in English (L2) lexical decision and were strongly decreased (but still significant) in both translation tasks. The authors concluded (in agreement with Elston-Güttler et al., 2005) that even in high constraint sentences, nonselective activation initially occurs, followed by lexical selection. Nevertheless, semantically rich sentences were apparently able to modulate the bilingual word recognition process in at least three different tasks.

Dijkstra, Van Hell, and Brenders (submitted) compared the reaction times and brain waves of bilingual participants during the processing of sentences and target words in both L1 and L2. In their study, sentences were presented to the Dutch-English participants word by word (RSVP). In the reaction time variant of the experiment, the participants had to decide if the last presented item was an English word or not (English lexical decision). In the EEG variant, the participants silently read the sentences (and a continuation) word by word. The mean response time for the target word did not differ much when the introductory sentence was English or Dutch. This suggests that the effect of a language switch *as such* on the reaction time to a subsequent target word may be limited.

Nevertheless, a non-identical cognate like 'apple' was processed faster in the sentence context than a comparable control word that exists in only one language. This cognate facilitation effect was found to be larger in the English sentence context than in the Dutch context. This was also the case when the task was to decide if the target word ('*appel*') belonged to Dutch rather than English. This study therefore suggests that the Dutch sentence context leads to a stronger constraint than the English one. The currently available studies suggest that a high-constraint sentence context may reduce the cognate facilitation effect, but it did not completely disappear in all studies.

The study also examined how the EEG responded to language switches (also see Moreno, Federmeier, and Kutas, 2002, and Proverbio, Leoni, and Zani, 2004). Again, depending on the sentence context, cognates showed different patterns than control words. After a predictive English sentence context, the English version of the cognate turned out to be easier to integrate than a control word (as reflected in the N400-effect, a marker for ease of semantic integration). However, following a Dutch sentence context, the reverse happened: The English cognate was more difficult to integrate. In sum, both the reaction times and EEGs in this study indicate that sentence context may modulate effects of word type (cognate status). Differences in the results for the two dependent variables indicate there is a difference between early identification processes and later decision mechanisms.

To summarize, currently available bilingual sentence studies appear to agree that sentence context can modulate the bilingual word recognition process, but it is still unknown which factors affect the degree of exerted modulation and how they interact. Among the obvious candidates are the sentence materials used in the studies at hand (e.g., their semantic constraint), the word materials involved (e.g., cognates mixed with one-language words or not), the L1 and L2 involved (e.g., English, Dutch, or Spanish), and the applied experimental techniques and methodologies (e.g., RSVP with lexical decision, naming, or eye-tracking). Which of these factors are responsible for the differences across studies is currently unknown.

8. The multilingual lexicon: Present and future research

In the course of this chapter, we have answered the questions about the word recognition system of multilinguals that we posed in the introduction. The answers that can be provided on the basis of present evidence are the following. The word forms, meanings, and grammars of different languages are, most likely, not stored in different databases, but in one integrated lexicon. Of course, this conclusion does not mean that 'burgemeester' (Dutch for 'mayor') and 'shoe' (English) will have one shared representation, simply because the two items do not share any word form or meaning characteristics. For the same reason, they will not affect each other's recognition to a great extent. In this respect, the bilingual case is not different from the monolingual situation, where ‘mayor’ will not affect the recognition of ‘shoe’ either.

Instead, language nonselective lexical access implies that words that are close in form and/or meaning will affect each other’s recognition irrespective of language. This has become evident in our review of the processing of cross-linguistic neighbors, cognates, and false friends. Cross-linguistic effects have been observed in reaction times, error rates, brain waves, eye movements, and a host of other dependent variables. Evidence from neuro-imaging studies involving Event Related Potentials and fMRI so far suggests that also in the brain, language membership is a less important ordering principle than, for instance, phonology or semantics (see, e.g., Indefrey, 2006). The integrated nature of the lexicon also implies that switching between languages must imply the inhibition of the unwanted language (Green, 1998) or the application of decision criteria that make use of language membership information (e.g., Dijkstra, 2005; Roelofs, 2002; Smits et al. 2006).

The integrated nature of the lexicon leads to advantages and disadvantages for bilinguals relative to monolinguals. On the one hand, multilinguals are able to communicate in more languages than one, which facilitates, for instance, their affairs in international trade, their acquisition of new scientific knowledge via the Internet and international journals, and their awareness of cultural and societal differences. On the other hand, speaking several languages regularly must imply that the amount of time spent on use of the mother tongue, is substantially less than when only one language is spoken. In the long run, this reduced frequency of usage must have consequences for processing latencies, speech errors, and tip-of-the tongue phenomena in the mother tongue (Dijkstra, 2003; Gollan & Acenas, 2004; Gollan & Brown, 2006; Poulisse, 1999; Randsdell & Fischler, 1987). Speaking a foreign tongue may also imply that language use in the mother tongue is gradually affected (‘contaminated’ some would say) by the word forms, conceptual distinctions, and grammatical rules from the other language. An increase in the L2 proficiency and number of L2 speakers may even have societal consequences. For instance, it has been argued that the English language in Europe is affected by the contribution of L2 speakers with a variety of L1’s, perhaps in the long run leading to the development of a variant we might call ‘euro-English’ (De Swaan, 2001; Van Oostendorp, 2002).

We end this chapter by noting that research into multilingualism is expanding quickly. A topic that is receiving increasingly more attention in Europe is the acquisition of a foreign language at an early age. In the Netherlands, for instance, all children of about 11 years of age, from grades 5 and 6, already take English lessons (and in multilingual schools, even earlier). It is possible to measure the EEG of such children with special electrode caps. It turns out that already after a very short learning period, the children’s brain exhibit waves that are similar to those of adults. They are sensitive to semantic relationships between words in sentences and to morphosyntactic violations in sentences (Brenders, Van Hell, & Dijkstra, in preparation).

Second language acquisition can be seen as part of a broader topic for which the time has come: the consequences of multilingualism for cognition and cognitive change across the life span. Bialystok and colleagues (2001, 2004, 2007) argue that multilingual children are better than monolingual children in handling ambiguous figures, probably because they are exercised in the discrimination of complex information of different languages. Late in life, multilingualism may help to reduce the consequences of cognitive decline and possibly delay the first symptoms of Alzheimer's disease by some years. On the other hand, adult and ageing bilinguals might suffer more from word fluency problems than monolinguals do. The multilingualism of ageing is, in brief, a research domain that needs to be explored in a western world in which the elderly become more and more prominent.

In this context, we should no longer consider language and multilingualism in isolation from other cognitive abilities. Indeed, the focus of psycholinguistic research is shifting from the separate components of language processing to the interaction of these components with social-cognitive and emotional aspects in 'ecologically valid' situations across the life span.

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Index

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