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1 *The cognitive neuroscience of language: challenges and future directions*

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1.1 Introduction

Does the brain hold all the answers to the questions that puzzle, intrigue, and delight us about human language? In some sense this has to be true: both the questions we pursue and the answers that we seek are to be found in the brain. Where else? Still, it is good to remind ourselves that not so long ago the study of the brain was deemed irrelevant for the study of cognition. In fact, it is rumoured that this still is received opinion in some corners of the world. And why not? After all, leaving aside (at our peril) neuropsychological work for the moment, a great deal of what we know about the structure and functioning of the language system has come from research that has essentially ignored the fact that language is seated in the brain. And we should acknowledge that today, even after the explosive growth of ever more sensitive and revealing brain-imaging technology, a cognitive neuroscience approach to language has not as yet merged with linguistic and psycholinguistic research programmes.

There are, however, good reasons to believe that such a merger would be beneficial for our understanding of the language system. For example, neurobiological data can provide evidence on the neural reality of the representational levels that are distinguished by competing language models, such as the disputed separation between syntactic and semantic knowledge. These issues can be addressed by positron emission tomography (PET) and functional magnetic resonance imaging (fMRI) research on the neural systems related to different kinds of linguistic knowledge. Such evidence is directly relevant for fundamental claims on the basic architecture of the language system. Neurobiological data are also relevant for long-standing debates on the domain specificity of language (for example on the putative existence of a dedicated verbal working-memory system, or of a dedicated system for recognizing speech sounds). In addition, various measures of neurobiological activity deliver fine-grained temporal information on the processing dynamics of language production and comprehension. Such information is crucial for assessing the different claims of sequential number of active research centres, ERP research on sentence-level syntactic and semantic processing is providing revealing data. This work is discussed in the chapter by Hagoort *et al.*, that also includes a review of PET and fMRI experiments on sentence processing. Almost all of this work is, however, limited to language comprehension. Research on the production of complex sentences awaits attention from psycholinguists and cognitive neuroscientists alike.

1.3 Mapping language in the brain

The cognitive neurosciences owe their sudden expansion to the increasing availability and sophistication of functional brain-imaging methods (we use the term 'functional brain-imaging' generically, to include all non-invasive measures of human brain activity). Part of the excitement that has accompanied these technical developments has been fed by the hope that they will provide a direct window on the brain/mind in action. There is some justification for this hope. PET and fMRI provide unrivalled possibilities to map language-related areas in the living, undamaged human brain, and ERPs (together with event-related fields, ERFs, the magnetic counterparts to ERPs, obtained from the magneto-encephalographic activity of the brain, the MEG) reflect neurophysiological activity at the millisecond level that can be reliable related to real-time cognitive processing. Together, these methods provide spatial and temporal data that can be directly applied to the general questions of the cognitive neurosciences: what is happening where and when in the brain? But next to their obvious value, it is important to appreciate the limitations and problems of brain-imaging methods. The chapter by Rugg discusses the strengths and weaknesses of PET, fMRI, ERPs, and ERFs. In addition, Rugg raises several general issues regarding the application of functional brain-imaging methods in cognitive neuroscience. Among these are the need to integrate spatial and temporal information, the problem of deciding what constitutes a real difference in brain activity (in particular, a difference that warrants the assumption of functionally distinct (sub)systems or operations), and the fundamental problem of moving from a neural correlate of cognition to a causal relationship between neural and cognitive activity.

Some of the issues that are raised by Rugg are taken up in the chapter by Kutas *et al.*, and the chapter by Büchel *et al.* Kutas and colleagues focus on the use of ERP and ERF data to understand language processes. The shapes and spatial distributions of electromagnetic activity provide a rich collection of ERP and ERF components that have been linked to different aspects of the language system. Kutas *et al.* discuss ways to compare and decompose the spatial distributions of electromagnetic data, and to map from spatial distributions to underlying neural generators. This mapping from surface recordings to neural tissue is often considered to be the Achilles heel of electromagnetic measurements: although ERPs and ERFs are unmatched in their temporal resolution, they lack spatial resolution. Kutas *et al.* critically discuss different kinds of neuronal localization approaches, from which it becomes clear that in fact substantial spatial information can be derived from electromagnetic data, given appropriate boundary conditions. This is one of the areas where much is to be expected from combining information from different brain-imaging measures. In particular the use of fMRI to constrain the solution space for electromagnetic localization procedures seems promising. Of course, this kind of combined approach critically assumes that we can sensibly relate the signals measured by fMRI and EEG or MEG, which is one of the issues discussed by Rugg. The combination of the millisecond precision of electromagnetic recordings with specific neuronal foci would be a big step towards answering the 'where' and 'when' questions.

The combination of 'where' and 'when' relates to another fundamental question on mapping language in the brain, namely the issue of interactions between brain regions. For a complex cognitive capacity such as language, it is beyond doubt that a variety of areas in the brain are going to be simultaneously active. Standard PET and fMRI analyses can reveal which areas of the brain were active during a particular period of time. However, a collection of activated areas does not by itself reveal which areas, if any, interacted. For this, we need to know two things. One, the functional connectivity, that is the temporal correlation between spatially remote neurophysiological events (which areas have correlated activity?). Two, the effective connectivity, that is the influence that one neuronal system exerts over another (which area modulates activity in another area?). This is the subject of the chapter by Büchel *et al.*, who introduce analytical procedures for characterizing both functional and effective connectivity. This is very much an emerging approach to the analysis of brain-imaging data, but it is an essential part of a cognitive neuroscience approach to language. If we are to succeed in our goal of tracking language in space and time in the brain, then elucidating the connectivity and interactivity of language-related cortical regions is of critical importance.

Amidst all the excitement that has been generated by the new brain-imaging technology, we run the risk of neglecting a fertile and prolific research area that has contributed, and is contributing, much to our knowledge of language in the brain. This is the neuropsychological tradition. The chapter by Saffran and Sholl shows how much information can be obtained from a detailed examination of the kinds of deficits that are associated with particular lesion sites. Their chapter is on the architecture of semantic memory, focusing on impairments in word meaning. The evidence that Saffran and Sholl review shows that semantic information is distributed over several areas in the brain, and that particular kinds of information can be localized to specific regions of the cerebral cortex. Interestingly, the lesion data indicate that areas outside the regions that are traditionally associated with language functions (i.e. the perisylvian cortex of the left hemisphere) are involved in semantic processing. In particular the inferotemporal cortex, possibly in both hemispheres, is clearly involved in the organization of meaning in the brain. As Saffran and Sholl point out, our knowledge of the functional and neural architecture of semantic memory that is being built up on the basis of lesion data, is finding support in brain-imaging experiments.

This converging evidence from brain-imaging and neuropsychological data highlights the importance of capitalizing on the combination of these two sources of and interactive processing models. In principle, then, we stand to gain a lot by taking a cognitive neuroscience perspective on language.

However, the field of language and brain research is at present quite fragmented, and has by no means reached maturity. In part this can be attributed to the separate histories of linguistics, psycholinguistics, and the neurosciences, which has not been conducive to cross-talk. Furthermore, cognitive neuroscience is still very much under development, with several conceptual, analytical, and neurophysiological issues not yet worked out. However, there has also been a certain unawareness, perhaps neglect even, of linguistic and psycholinguistic work by the neuroscience oriented disciplines. What we hope to achieve with this book, is to serve two sides of the emerging cognitive neuroscience community: those who have entered into the field of language from a more neuroscientific background, and those who are in the process of including a neurobiological perspective in their own work on language. Accordingly, this book includes an explication of the language system from a linguistic perspective, and state-of-the-art overviews of the cognitive architectures of speaking, listening, and reading. These foundational chapters reflect our belief that progress in the cognitive neuroscience of language is best achieved when our research questions are based on linguistic theory and psycholinguistic models, with a clear understanding and appreciation of the various factors that can affect comprehension and production. At the same time, given the complexities of brain-imaging work, neuroscience technology cannot be taken on board lightly by language researchers. Therefore, the book also presents theoretical and empirical discussion of language-related brain-imaging work, both as a review of our current knowledge, and as an explication of the specific problems that confront language researchers when they incorporate brain-imaging technology into their research.

The particular collection of chapters is motivated by several overarching themes that we see as being critical for the development of a cognitive neuroscience approach to language. These include the complexity of language, the mapping between measures of brain activity and the language system, and the issue of functional and anatomical variability.

1.2 Complexity

Despite the critical and central role that language plays in almost all aspects of human life, results from cognitive neuroscience research on language are not leading the field. Why is this? One obvious reason is that we lack an animal model of language. This severely limits our ability to investigate the neural foundations of language, excluding among others the standard neuroscientific repertoire of cell recordings, ablations, and the like, which have proven so fruitful in furthering our understanding in other areas.

A more fundamental reason emerges from the complexity of the human language system. Based on almost a century of linguistic and psycholinguistic research it is clear that language in action involves the activation, co-ordination, and integration of complex representational systems (such as for sound, orthography, grammar, and meaning), operating at millisecond speed. The chapter by Jackendoff introduces the various representational levels that need to be distinguished, and discusses their interrelationships. The so-called blueprint chapters by Levelt, by Cutler and Clifton, and by Perfetti provide overviews of our current knowledge of the cognitive architectures for speaking, listening, and reading. Together, these four chapters present specific theories and working models of the representations and processes that define language. These chapters also describe a variety of variables that are thought to play a role during comprehension and production, discussing strengths and weaknesses of experimental paradigms and tasks, and mentioning several gaps in our current knowledge. In doing so, they set a large part of the scene for a cognitive neuroscience research programme on adult language comprehension and production.[1] Of course, various aspects of the models may turn out to be incorrect, and some of the variables and tasks may in fact be artifactual or irrelevant. Be that as it may, when we design brain-imaging experiments on language, a major concern should be the relationship between the chosen design and task(s), and the cognitive architecture of the language faculty, against the background of the accumulated linguistic and psycholinguistic knowledge. We think that it is fair to say that this concern has not always been carefully considered in the brain-imaging literature. For example, the common use of the verb-generation task as a presumed window on semantic aspects of the language system can be seriously questioned on both theoretical and empirical grounds (see the chapters by Levelt and by Price *et al.*). Likewise, the mapping of meaning in the brain on the basis of a comparison of brain activity elicited by undifferentiated, broad categories of word types runs the danger of underestimating the complexity of the semantics of language, as becomes clear from the discussion of semantic impairments in brain-damaged individuals in the chapter by Saffran and Sholl.

There is, moreover, another side to the brain-imaging and language complexity issue. Although, as we just noted, the complexity of language should not be underestimated, it also needs to be met head on by the cognitive neuroscience community. The situation to date is that the large majority of PET and fMRI language studies have focused on single-word processing. This is perhaps understandable from the desire to perform a 'simple' experiment (although as various chapters in this book show, the presumption of simplicity is often unwarranted; for example, the search for 'words in the brain' cannot be lightly undertaken, as is discussed by Price *et al.* in their overview chapter on brain-imaging studies of lexical processing). However, language is much more than the processing of single words. Words are indispensable vehicles of communication, but the primary goal of speaking, listening, and reading lies in the message that is to be produced and understood. Message-level production and comprehension requires the activation and real-time co-ordination of several levels of linguistic and non-linguistic information. This complexity is central to the essence of language, and presents a major challenge to cognitive neuroscientists, which has to date basically not been taken up. There is one emerging area here, which is the work on event-related brain potentials and sentence processing (ERPs are components of the brain's electroencephalographic activity, the EEG). Although still relatively modest in terms of the information. Brain-imaging data can reveal which distributed areas of the brain are associated with the performance of a particular task, such as understanding a spoken sentence. However, these data do not indicate whether all of the active areas are essential to the task at hand. This is where neuropsychological data can provide critical information, by determining whether a damaged area was indeed crucial for the lost function (note that this still does not necessarily imply a direct relation between the damaged area and the proposed function). However, neuropsychological data do not reveal which other areas are normally involved in the impaired function. In short, the combination of brain-imaging and neuropsychological data provides the best basis for mapping language in the brain.

1.4 Anatomical and functional variability

In addition to the constraints, validations, and extensions that brain-imaging data can bring to cognitive models of language, it is a topic in its own right to investigate the neuroanatomy of language-related areas in the brain, and to unravel their connectivities. The human brain is the one and only organ to have developed a rich and varied system of verbal communication, and this raises questions about the neuroanatomy of this unique ability. Moreover, neuroanatomical knowledge can shed new light on the structure and functioning of the language system, in part by providing evidence on the morphological commonalities and differences among the cortical and subcortical areas that emerge in brain-imaging studies of language. The chapter by Uylings *et al.* is a good example here. These authors show that the classical, and not always uniform, definition of Broca's area needs to be reconsidered in the light of detailed anatomical information. It appears that several architectonically distinct areas have been subsumed under the heading of 'Broca's area'. This raises questions about the functionality of this cortical region, and is directly relevant for brain-imaging research that has linked a diversity of language operations to the overall region of Broca's area (see the review of the PET and fMRI literature in the chapter by Hagoort *et al.*).

An additional and critical contribution from detailed neuroanatomical work lies in assessing interindividual variability. It is now beyond any doubt that there is considerable variability among individual brains in the size and location of cortical areas. This also holds for the classically-defined Broca's area, as is demonstrated by the work of Uylings and his colleagues. The brain-imaging community still has to come to grips with these neuroanatomical differences. At present, the common approach is to map individual brain activations into a standardized brain atlas, and to define locations by reference to a co-ordinate system, usually the Talairach system. This approach does not define cortical regions as anatomical, cytoarchitectonic areas, and glosses over neuroanatomical variability between individuals. To some extent these issues can be resolved by fMRI measurements, where anatomical and functional information can be mapped for an individual brain. However, the basic problem of comparing subjects remains: we need to know whether one individual's foci of activity are located in anatomically the same or different areas of the brain as the foci obtained for another individual. One approach is to use a three-dimensional human brain database, incorporating detailed anatomical information from different brains, on the basis of which a probability map can be computed that takes variability in size and location into account (cf. Roland and Zilles 1994).

1.5 Future directions

In the preceding sections we have discussed some of the issues and themes that are central to the emerging field of the cognitive neuroscience of language. Although still a young effort, quite a lot has already been achieved, and several of the issues that are addressed in the chapters of this book point the way to future trends. In this final section, we want to draw attention to some challenges and future directions for research that are at present almost *terra incognita*, but that will hopefully receive some impetus from the theoretical and empirical work that the book presents.

The starting point for future directions lies in the need to take a more integrated approach towards language. This holds for our measurement and analytical procedures, and, most importantly, with respect to core characteristics of language in action (e.g. multiple activation of different knowledge bases, incremental and millisecond-level processing, integration among different representational systems and processing streams). An integrated approach requires considerable ingenuity in terms of experimental design (certainly with PET and standard fMRI measurements, that require blocked presentation of stimuli; event-related fMRI is more flexible in this respect, as are the ERP and ERF methods). In addition, it requires the combination of different measurement techniques, preferably in the same subject, and for some issues perhaps even at the same time.

The call for combined PET/fMRI and ERP/ERF measurements is often heard. It is thought that this kind of combination will help to overcome the spatial or temporal limitations of individual brain-imaging techniques. In principle this certainly is true, but we need to be aware that at present we have insufficient understanding of how the haemodynamic signals (measured by PET and fMRI) and the electromagnetic signals (measured by EEG and MEG) are related. This makes it difficult to determine the nature of the relationship between a particular component of the ERP/ERF signal and a haemodynamic response in a specific area of the brain (see the chapter by Rugg for further discussion). Nevertheless, an integrated spatiotemporal approach holds considerable promise. In the immediate future, progress can be made by devising experimental designs that allow the same stimuli and presentation procedures to be used in separate ERP/ERF and PET/fMRI experiments. For example, fMRI data can be used to constrain the solution space for neuronal source localization procedures based on ERP/ERF data. Analyses of effective connectivities in the fMRI data will help to identify the relations and constraints among activated cortical regions, some of which will be further defined by cytoarchitectonic data. If the experiment is appropriately founded in a model of the cognitive architecture, then by putting these different sources of data together we will be able to start building up a picture of the localization and the temporal dynamics of language in the brain.

There are other benefits to combining brain-imaging measures. One of these has received almost no attention in the literature so far. It concerns the use of ERPs as diagnostic tools for the evaluation of the processing activity measured by PET or fMRI. As is reviewed in part in the chapter by Hagoort *et al.*, ERPs have proven sensitive to distinct aspects of language processing. For certain components of the ERP waveform we now have a good understanding of their relationship to the language system (e.g. the N400 as an index of aspects of semantic processing, the P600/SPS of syntactic processing). This means that we can use ERP componentry to inform us about the processing impact of the language stimulation that we use to elicit a haemodynamic response. At the very least this provides an independent validation of the effect of the stimulation conditions during a PET or fMRI experiment. But it also opens the way to avoiding the use of extraneous task demands to evoke an overt response (such as judging the grammaticality or meaningfulness of a sentence). Often these tasks evoke additional processes that are not intrinsic to the processes that the experimenter is interested in, and that are moreover not well understood. This can considerably complicate the interpretation of the data. A grammaticality judgement task, for example, is by no means simple or focused on 'just grammar', but involves numerous representations and processes. ERP measurements can be helpful here, because reliable language-related ERP effects can be measured in the absence of additional task demands. For example, if subjects are instructed to listen attentively to sentences, without any further task, manipulating the semantic or syntactic context results in clear N400 or P600/SPS effects. The coregistration of PET/fMRI and ERPs can, therefore, open the way to language experiments that are less plagued by extraneous task demands.

The emphasis on more natural language experiments is related to another direction for future research, namely brain-imaging experiments with spoken language. The majority of imaging studies have focused on written language, following a long-standing bias in the psycholinguistic literature. This neglects the primacy of spoken compared to written language (despite its automaticity in most literate adults, reading remains an acquired skill, requiring explicit training). However, there is little reason for this neglect in a cognitive neuroscience research programme. The commonly used brain-imaging techniques are well suited for research on spoken language (although the noise generated by the current MR scanners does present some practical problems). Moreover, several decades of psycholinguistic work has provided a firm cognitive basis for research on spoken language comprehension, as is exemplified in the chapter by Cutler and Clifton. The time is more than ripe, therefore, for brain-imaging experiments in this area.

The situation is more complicated for language production research. Not because there is insufficient empirical and theoretical basis. Although language production has traditionally been less widely studied than comprehension, the chapter by Levelt presents a detailed cognitive model of speaking, together with convincing experimental support. The problems here are more practical in nature. Unlike listening or reading, speaking involves quite some facial movement, in particular of the jaw, lips, and tongue. And unfortunately, the standard brain-imaging techniques are quite susceptible to movement artefacts. For ERPs it is clear that substantial contamination can result (but possibilities to solve this by, for instance, digital filtering have been insufficiently explored). For ERF measurements less of a problem is claimed, although head movements under the MEG sensors remain very problematic. The extent of the problem in the case of PET and fMRI is unknown. Despite the frequent reaction in the brain-imaging community that speaking in the PET or MR scanner is out of the question, it is not clear how great the problem actually is. Certainly, if the position of the head relative to the registration device changes too much during the measurement, then this is very problematic. However, whether relatively small jaw, lip, and tongue movements create similar problems remains to be demonstrated. In fact, work within our own research group indicates that if subjects are asked to whisper, which naturally suppresses large articulatory movements, reliable and replicable PET and fMRI measurements can be obtained (e.g. Indefrey *et al.* 1998). A recent review of the PET and fMRI literature by Indefrey and Levelt (2000) indicates that in single-word production tasks reliable measurements can be obtained. It is, therefore, premature to rule out the use of the full battery of brain-imaging techniques in production research. But this clearly is an area where the more cognitively oriented work will have to be based on systematic investigation of the possibilities and limitations of the technology with respect to the act of speaking, in particular the production of full sentences.

A final and still very open area for future language research concerns neural plasticity, by which we mean the ability of the brain to compensate for damage by the reorganization of intact (sub)cortical areas. Aphasia is an obvious starting point for investigation here, although dyslexia and certain aspects involving language-learning impaired children also present interesting challenges. Another window on plasticity is the neural organization of language in deaf children and adults (cf. Neville *et al.* 1997). The general question with respect to aphasic patients concerns the role of non-damaged brain tissue in subserving the remaining language competence. Can intact brain tissue in part compensate for the loss of function in the damaged areas? This is a complicated issue, all the more so since brain damage as such does not have to directly involve language regions. Instead, damage could for example result in a limitation in the processing capacity (e.g. working memory) that is available for language, thereby indirectly leading to a language deficit. Progress in this area will critically depend on basing the research on a well-founded cognitive model of normal language processing, and on a firm understanding of the neurophysiological manifestations of normal and impaired language processing.

Not all of the areas for future research that we have discussed here are represented in the following chapters. In several cases that would have been premature. What we hope is that this book will help towards the further development of these exciting and challenging areas, and, more in general, towards the coming of age of a cognitive neuroscience approach to human language.

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Notes

1. An obvious gap in the coverage of this book is language development, both in the first and in the second language learner. Although steps towards a more biologically-based understanding of language development are being taken (cf. Johnson 1993), this is even more an emerging field than research on brain and language in adults. We hope that with this book we will contribute to a more concerted and psycholinguistically motivated approach to the cognitive neuroscience of language, and thereby provide relevant information for developmental research.

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