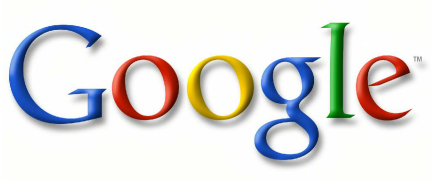

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LANGUAGE, BRAIN AND VERBAL BEHAVIOR. NEUROBIOLOGICAL ASPECTS OF LINGUISTIC CAPACITIES AND LANGUAGE PROCESSING

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Language, Brain and Verbal Behavior. Neurobiological Aspects of Linguistic Capacities and Language Processing

Editor

Joan A. Argenter

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Sergio Balari holds a Ph.D. degree in Philosophy (Hispanic Philology) from the Universitat Autònoma de Barcelona. Since September 1993 he has been a Professor of General Linguistics at the same university. From 1987 until 1991 he was a member of the Spanish team in the EUROTRA (machine translation project).
His main research topics move between Computational Linguistics and Grammar Theory. As a member of the EUROTRA Project, Sergio Balari worked in several areas both theoretical and applied, of natural language processing in the framework of unification-based grammar formalisms. We can emphasize his participation in the design of the Constraint Logic Grammar formalism, whose latter versions have been adopted as a standard in some European Union Projects.
During 1991 and 1992 he was a researcher at the University of the Saarland in Saarbruecken (Germany). His stay was financed by a CIRIT scholarship. During this period he wrote his Ph.D. thesis about the agreement relations in unification-based formalisms, supervised by Prof. Hans Uszkoreit and Prof. Josep Maria Brucart.

Sergio Balari has continued his research both on the theoretical and applied aspects of language processing and grammatical theory. We can point out his participation as a coordinator (jointly with Josep Maria Brucart) of the Universitat Autònoma de Barcelona team in the European Project LATESLAV for the development of advanced grammar checkers and his participation as editor and author in the book *Romance in HPSG.*

Dominique Cardebat is a linguist; she obtained her Ph.D. at the University of Toulouse Le Mirail and has been working, for 10 years, as a Senior Scientist in an INSERM (Institut National de la Santé et de la Recherche Médicale) unit that is located in the department of Neurology of Toulouse University Hospital (Purpan Hospital). Her main topic of interest is psycholinguistics processes in brain-damaged patients, especially at the lexical semantic level. Her works consist in a two-fold approach combining cognitive neuropsychology and functional neuroimaging.

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Albert, M. L. and Obler, L.K., *The Bilingual Brain: Neuropsychological and Neurolinguistic Aspects of Bilingualism.* New York: Academic Press, 1978.

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Jordi Peña holds a degree in Medicine and Surgery from the Universitat Autònoma de Barcelona and a MD from the Universidad de Navarra. He studied Neurology with Prof. L. Barraquer-Bordas and at the Hospital de Bellvitge. As a medical student he was already very interested in Neuropsychology and Behavioral Neurology. He also studied the Russian language and translated «Neurolinguistics» by A.R. Luria into Spanish. He got a scholarship from the French government to work at the Hôpital de la Salpêtrière (Prof. Lhermitte and Signoret) (1975). From 1980 he has worked attending physician at the Institut Municipal d'Assistència Sanitària (Hospital del Mar and Centre Geriàtric). He is also an associate professor at the Universitat Autònoma de Barcelona. He has developed and validated a methodology of Neuropsychological Assessment, the Barcelona Test (1980-1996). He has published eight books, including: A textbook on Neuropsychology, a handbook on Logopedia and a book about the rehabilitation of aphasia. He has published more than forty articles in journals such as: *Revista de Neurologia, Revue Neurologique, Brain and Language, Aphasiology, The Clinical Neuropsychologist, The Journal of Neurolinguistics.*
Currently he works on the reading and writing disorders (in an international project) and Alzheimer's disease (methods of diagnosis and pharmacological treatment). He is a member of several professional societies such as the Societat Catalana de Neurologia, Sociedad Española de Neurologia, Société de Neuropsychologie de Langue Française, the International Neuropsychological Society, the European Society of Neurology and the Societat Catalana de Neuropsicologia.

Friedemann Pulvermüller is Heisenberg-fellow at the Institute of Medical Psychology and Behavioral Neurobiology of the Universität Tübingen. His work focuses on the neurobiology of language, in particular the questions of how phonemes, syllables, words, syntactic categories and sentence structures are represented and processed in the human brain. In addition, he has done work on related topics in cognitive neuroscience, in particular on visual form perception, and on therapy of neuropsychological syndromes. His books *Aphasische Kommunikation* and *Neurobiologie der Sparche* appeared in 1990 and 1996, respectively.

Núria Sebastian is Professor of Basic Psychology at the Universitat de Barcelona. Her research focuses on the mechanisms of perception, production and acquisition of speech and on the mechanisms on which the phonological characteristics of each language depend. She is in charge of a quality research group at the Universitat de Barcelona, and collaborates with numerous research groups, among them we can emphasize the one with the Laboratoire de Sciences Cognitives et Psycholinguistique (LSCP) of the Centre National de la Recherche Scientifique (CNRS, Paris) and with the Institute Max-Planck of Psycholinguistics in Njimegen (The Netherlands). The scientific methods she uses include the behavioral types as well as mental imagery (PET scan and Evoked Related Potencials (ERPs)). Recently her research group has begun the first laboratory on acquisition of language in babies in the country.

Language, Brain and Verbal Behavior

Joan A. Argenter
Institut d'Estudis Catalans

This book presents some of the results of the meeting which, under the title of «International Workshop on Language, Brain and Verbal Behaviour: Neurobiological Aspects of Linguistic Capacities and Language Processing», brought together at the Institut d'Estudis Catalans (Barcelona, 28 and 29 November 1996) some of the scientists who best represent the research on the problems, foundations and methods of Neurolinguistics, or the systematic study of the relationships between brain and language. The meeting attracted a varied audience of linguists, neurologists, psycholinguists, speech therapists and other professionals, as well as students of these disciplines, who followed the presentations with interest and attention and joined in with debates not reproduced here.[1]

The meeting formed part of —opened, in fact— one of the many new initiatives recently undertaken by the IEC: the «Jornades Científiques de l'IEC», the purpose of which is to deal with questions currently of special interest for a particular field of research or ones that have an acknowledged social impact.

In my view, this Workshop more than accomplished both goals: in the first place, human language is a sufficiently central phenomenon of human nature for its study to awaken an intrinsic intellectual interest, and at the same time, linguistics is one of the most dynamic spheres of research within the human sciences. Moreover, the brain is similarly an immensely exciting world, still imperfectly understood, but one in which every small advance in knowledge generates a host of questions and opens up a host of perspectives. The study of the relationships between language and brain is of dual interest, and has consequences of incalculable human and even social value at a time when increased life expectancy is prompting a growing need to guarantee

1. In the present edition we reproduce the comments to the lectures by the assigned speakers. The texts of the discussions have been delivered to us by the authors, except for the comments on Prof. Pulvermüller's paper by Prof. M. L. Kean, which have been transcribed from the session's recorded tape.

I would like to thank Ms. Neus Portet for her invaluable help in the process of both the edition of this book and the workshop itself.

life's most prized quality: the integrity of the cognitive abilities or the maintenance of the individual's powers of reasoning.

Thinking about language, understood as a global phenomenon, is a privileged field in which the humanities and social disciplines converge with those traditionally regarded as prototypically scientific. Amongst the former, *primus inter pares*, is linguistics, although it is not the only one. In fact, linguistics is a discipline which cannot be said to have failed to absorb fruitful ideas from other fields or to sow its seeds in other areas of knowledge. From the interaction between linguistics and other specific disciplines there emerge overlapping areas different in nature and with different results, and areas of research that are clearly differentiated from one another and linked in diverse ways. This interdisciplinary phenomenon is good not only because it makes us consider our usual paradigms in a more relative way, but also because it opens up fields of research which otherwise could never have emerged.

During this century we have witnessed the development of a double perspective in the scientific approach to the problems that concern us. At the beginning of the century, partly under the impetus of the phenomenological revolution, psychology, logic and linguistics showed us that mental processes or brain functions such as perception, reasoning and language could be studied and described on the basis of structural regularities and formal patterns, independently of their notional content. The cognitive revolution that took place in mid century made it clear that these functions can also be studied independently of their respective physical and biological bases. The metaphor of the brain as hardware and the mind as software has been fruitful in heuristic terms and also because it has helped to narrow the gap between the humanities and the computational sciences. This paradigm has favoured the development of a «top-down» methodology, that is to say, from software to hardware, the methodology proper to the so-called cognitive sciences. However, the development of a methodology in the other direction, from «bottom-up», or from the human hardware to its software, is not unthinkable, while paying attention to questions about the neurobiological bases of language and the problems arising therefrom. This is the methodology proper to the so-called neurosciences, and the one mainly applied in the papers collected here.

The cognitive revolution of the mid century significantly affected linguistics: on the one hand, language was conceived as a system of knowledge of the human mind which underlay verbal behaviour and, ultimately, made it possible, and the subject of study was understood to be this very specific linguistic knowledge: that is to say, intuitive not reflective knowledge. On the other hand, very powerful elements of formal description were introduced: the theory of recursive functions. The system of representation of this knowledge, which was called grammar, had to be, then, a finite system capable of enumerating recursively or generating an infinite number of linguistic objects (the sentences of a language). The distinction between the internal language, as a finite cognitive system, and the external language, as a set of empirical or uttered objects (Chomsky, 1986), was based on and was a formalisation of intuitive ideas already expounded by W. von Humboldt more than a century before.

What do we understand by the intuitive linguistic knowledge of an individual? A way of explaining it would be to focus on a specific example from the Catalan language and attempt to make explicit what a Catalan speaker knows in relation to the specific case.

Now consider this Catalan sentence:

En el programa d'avui, el doctor Corbella tractarà de les relacions sexuals prematrimonials amb la Mari Pau

«In today's programme, Dr Corbella will discuss premarital sexual relations with Mari Pau.»

It is precisely thanks to their linguistic knowledge that when hearing this sentence uttered, any Catalan speaker would be able to identify a continuum of sound as a significant sentence in Catalan. Any Catalan can segment this sentence into sequences of significant and well-formed sounds which we usually call words. Any Catalan is able to assign, systematically rather than randomly, constant meanings to these words and to the sentence as a whole. They are able to group the words in the right way so as to deduce particular meanings, without in fact there always being phonic markers to indicate the appropriate groupings.

To be specific: Our anonymous Catalan speaker knows that *programa* is a polysemic word, but can guess from the context that what it means here is a radiophonic or televisual space; he or she knows that the word *corbella* designates a sickle but is also able to exclude this interpretation, since all Catalans know that *doctor*, here, is a title, and, therefore, that what follows is a surname and not a common noun or first name, and that surnames do not designate classes of objects; they know that *tractarà* is a verb and that its particular form projects the whole sentence towards the future, that *relacions* is a noun, that its particular form designates more than one relationship, and that *sexuals* is an adjective; they know that both the plural of the word *sexuals* and the plural of the word *relacions* are marked by the final *-s* and that, although *sexual* is a word in Catalan, *relacion* is not;[2] they know, however, that both words are regular formations; they know that the word *prematrimonials* is a derivative of *matrimoni*, that the suffix *-al* makes it into an adjective and that the prefix *pre-* gives it the meaning of before marriage; they know that the word *avui* denotes the day on which the sentence is uttered, that this coincides with the day on which the programme will be, regardless of whether it is Thursday or Friday or odd or even; they know that *Mari Pau* is the proper name of a person and denotes a single individual. Catalan speakers also know that the word *tractarà* and the words *de*, *el* or *la* —these latter often known as functional or grammatical words— are of a different linguistic nature. The anonymous Catalan knows all this, and more. For example, to be brief, they know that the utterance is ambiguous, since —according to how the prepositional phrase *amb la Mari Pau* is grouped— the utterance will have to be interpreted as meaning that Dr Corbella will discuss with Mari Pau the subject of

2. The singular of the Catalan word *relacions* is *relació*, but the plural is regular in so far as it is formed by applying the general rule to the underlying form which we may represent as ending with the suffix /ion/.

premarital sexual relations or will discuss the premarital sexual relations with Mari Pau he may have, or has had, or that people in general may have had with Mari Pau.

The anonymous Catalan would know all this even though in fact he or she did not know explicitly what a prefix or a verb or a proper name is, and all this would form part of the knowledge that that sound sequence activates in his or her mind.

Determining the identity of the individuals named would not form part of their linguistic knowledge —the sentence may be understood by someone who does not watch the Catalan TV channel— nor would precise determination of the day of the week or month to which *avui* refers, nor the interpretation most appropriate to the context (because in fact we have an utterance with no contextual specification), nor their moral stance with regard to premarital sexual relations.

Linguistics must specify what the substance is and, if possible, the form that this linguistic knowledge takes in our minds —and, in a word, in our brain— at a relatively abstract level of representation. So, to the extent that linguistics concerns itself with a system of specific knowledge rather than with forms of behaviour, it may be seen as part of cognitive psychology and this as part of human biology (Chomsky, 1980). The result is that the unified theory of language that linguists are endeavouring to build up, starting from a particular level of abstraction and on the basis of strictly grammatical data, will have to be compatible with an eventual theory of language elaborated from neurobiology, on the basis of data of a different type. This includes data from various forms of anomalous verbal behaviour in which the speaker appears to have lost or suspended significant aspects of the different types of linguistic knowledge just mentioned.

For neurologists, the study of the relations between brain and language starts at in the 19th century, with the works of Paul Broca (1861, 1865) and Carl Wernicke (1874) on aphasics, and their localizationist hypothesis, that is to say, the hypothesis that correlates particular forms of anomalous verbal behaviour with particular impairments on specific areas of the cerebral cortex. Aphasia is a specific verbal pathology consisting of an individual's loss of certain aspects of speech due to a cerebral lesion in the hemisphere that is dominant in verbal activity. The clinical description of the aphasias known by the name of those authors —Broca's aphasia and Wernicke's aphasia— is the foundation stone of the neurological approach to language understood as a function of the brain. Motor aphasia, characterised by serious disorders in speech production, is associated with Broca's area, a specific neuroanatomical structure located in the frontal region of the left hemisphere (in right-handed individuals) and receptive sensorial aphasia, characterised by serious disorders in understanding, with Wernicke's area, a different neuroanatomical structure, located in the temporal lobe also in the left hemisphere. The strict localizationist hypothesis, however, was replaced by Wernicke with the idea that the representation of language in the brain implied a flux of information between the two distant areas mentioned, and so was conditioned by activation of particular neuronal connections. This point of view was called the connectionist hypothesis, and in our century has been staunchly defended by Norman Geschwind (cf. 1974). This model has made it possible to explain several types of aphasia including the so-called conduction aphasia, in which the lesion actually affects the connection between the two areas.

Counter to these notions, a holistic approach has sometimes been put forward, in which verbal behaviour is understood as the result of an undifferentiated cognitive capacity and, therefore, difficult to locate in specific areas of the brain (Freud, 1891).

Roman Jakobson (1941; Jakobson & Halle, 1956) was the linguist who carried out a linguistic analysis of the pathological utterances of aphasics in the forties and fifties and produced an interpretation of the findings of Broca and Wernicke in terms of structural linguistics according to the descriptive paradigm of the period. For Jakobson, the data of the so-called anomalous or extraordinary forms of verbal behaviour —such as aphasias, children's language and poetry— illuminated, threw into relief, as it were, essential aspects of the linguistic structure of so-called normal speech. And what is more, they are an empirical validation of the minimal theoretical conception of structuralism (in itself, this was a set of analytical methods rather than a unified theory of language).

For Jakobson (cf. Jakobson & Halle, 1956), the functioning of language was based on two operations: the choice of linguistic units and their combination in the sentence. Language was structured around two axes: the axis of selection or paradigmatic axis, and the axis of combination or syntagmatic axis. Parallel to this, language disorders might affect the selection but not the combination axis -in which case semantically anomalous but well-structured utterances would be produced. Or it might affect the combination but not the selection axis -in which case the sufferer would choose semantically appropriate words but would lose the ability to construct grammatical sentences, combining them wrongly or omitting category markers or the obligatory grammatical relations, and displaying agrammatism, a kind of telegraphic speech, in so far as words and functional markers, inflections, etc. are missing. These pathological features coincide, more or less, with those described by Broca and Wernicke almost a century before.

Jakobson also formulated a theory according to which both the process of language acquisition in children and the process of loss and grammatical destructuring in aphasics obeys a hierarchical structure, that is to say the elements of grammatical structure are acquired and lost in a certain order: in one case this hierarchy is the reverse of the other. In other words, the process followed by aphasics in their disorder is the mirror image of the process followed by children in learning.

This hierarchy is independently motivated by typological reasons. Thus, in the sphere of the sound patterns of languages, which Jakobson studied in particular, the phonological features regarded as most central, such as the consonant/non-consonant or vowel/non-vowel distinction, is universal (in an empirical sense) while the rounded-unrounded distinction does not appear in all languages.

Although Jakobson's theory of regression has recently been questioned (e.g. Gleason, 1993, among others), in fact since Jakobson, the relationships between the contributions of neurology and linguistics have been far more closely scrutinised by specialists in each of these disciplines.

Some observations are relevant here. On the one hand, general features of linguistic structure in normal speakers and the functional characteristics of the non-impaired brain were deduced

from abnormal and impaired structures. In fact, we now know that in its immature state the brain is considerably plastic, and that the usual process of lateralisation or specialisation of the two hemispheres for specific functions (language and the rational component in the left hemisphere, the emotional in the right) admits certain alterations, especially in cases of early traumatism (Lenneberg, 1973). It has therefore been said that aphasia in children is qualitatively different from aphasia in adults (Gleason, 1993).

It is obvious that the study of aphasia must deal with the aphasic brain, but even though such study lies at the origins of Neurolinguistics, this discipline should be asked to produce a model of how language functions in the healthy adult brain unaffected by any pathology. In this respect, the development of molecular biology and the impact of the new technologies on medical sciences have substantially changed the outlook. The various techniques of functional neuroimaging (from electroencephalography to positron emission tomography or PET, amongst others) have made our brains more transparent than ever, permitting an approach to the phenomena based on observation of the brain's metabolism and electrical activity rather than on abnormal behaviour. An interesting problem that now arises is a methodological one: if the traditional and present-day methods of observation were to lead to contradictory results —which sometimes happens— it would still have to be ascertained whether they are actually giving us information about different realities; for example, the organisation of the brain's representation of language, on one hand, and language processing, on the other, as someone has ventured to suggest (Obler, 1993).

Secondly, the theory of the functioning of language on which Jakobson based himself has been superseded by new concepts, precisely ones more closely linked to the cognitive revolution.

Since the sixties, authors like the neurobiologist Eric Lenneberg (1966) have tried to find neurobiological justification for the formal theories of grammar elaborated by Noam Chomsky. Harry Whitaker (1970) formulated a neurological model of language functioning compatible with Chomsky's so-called standard theory (Chomsky, 1965). However it should be said that in some cases the interpretations of the facts were forced in order to fit them into theoretical models which, moreover, were rapidly evolving. In any case, it was entirely pertinent to ask questions such as whether aphasias actually affected linguistic abilities (the underlying cognitive system) or only the linguistic performance that stems from them.

This does not mean that the linguistic foundations upon which pathological verbal behaviours were interpretated should not be fine-tuned. In the explanation of agrammatism, the existence of semantically full words and of functional words had been assumed uncritically. In fact, it is not at all obvious that this distinction defines two natural classes of linguistic objects. So, contrary to the opinion current among neurologists and linguists, a reinterpretation of agrammatism as a phonological rather than syntactic deficiency was proposed, in view of the crucial role that was played by the notion of the phonological word. According to this interpretation, agrammatism is characterised by utterances which simplify a phrase into the minimum chain of phonological words (Kean, 1977, 1978).

In fact, today both linguistics and neurolinguistics understand language not as a single cognitive ability, but as a set of modular capacities that are relatively differentiated but in close interaction amongst each another as well as with other non-linguistic cognitive capacities (Chomsky, 1981, Fodor, 1982, Jackendoff, 1992).

While it is difficult to believe today that the linguistic explanation of the facts may be reduced to strictly neurological terms, the advances of neurolinguistics can been seen as an external justification for linguistic theories, on the clear understanding that, as Jakobson recommended, linguists and neurologists should avoid mixing up the terms of abstract linguistic description with those of neurological description. At another level, it is obvious, for example, that the neurologist does not seek to justify linguistic theories, but first and foremost pursues a therapeutic goal.

The fact that I have confined myself here to the problem of aphasias is because these are central linguistic pathologies, in the sense that they specifically affect verbal behaviour and leave the other abilities intact.

Other verbal disorders have also claimed the attention of neurologists and linguists, and in recent times the various senile dementias, such as Alzheimer's disease, are closely studied. In these cases, beyond the fact that we are witnessing processes of generalised regression of the cognitive capacities, we also see phenomena of linguistic destructuring, but unlike the aphasias, these are not sudden traumatic processes but gradual ones, which allow the loss of language to be described stage by stage in association with the state of general cognitive regression of the patient and which also imply factors of a pragmatic order (Hyltenstam & Stroud, 1993, Obler, in this volume).

Of particular interest to us is the case of language disorders in bilingual or multilingual contexts. To what extent, if any, are the cases of monolinguals and of bilinguals a question of differentiated situations with regard to the brain's representation of language? (Weinreich, 1970, Albert and Obler, 1978, Paradis, 1977, and also in this volume).

The studies that follow should have a bearing on our knowledge of these and other questions. As I have already said, they are the work of eminent, highly qualified international specialists in this area of interdisciplinary research, which is still so little pursued, in strictly quantitative terms, in the Catalan institutions. I invite you to read them in depth.

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Cognitive Neuroanatomy of Language

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Language-related functions were among the first to be ascribed a specific location in the human brain (Broca, 1861). Recently, high-resolution MR images were obtained (1994) by Cabanis et al., from the still preserved brain of the first patient described one hundred and thirty years before by Paul Broca, in 1865. The patient, called Leborgne, was also known by his nick-name «Tan-Tan», which was the only stereotypic oral production he could produce after his stroke.

It is possible to see on MR images how the very large lesion destroys a fair amount of frontal cortex and the underlying white matter, and spreads towards the head of the caudate, far beyond the limits of what we call Broca's area.

Brain/language Relationships : The «Aphasia Model»

Over the past century, many attempts have been made to find clear relationships between aphasia and brain lesions, that is to use aphasia as a pathophysiological model to study brain/language relationships. As we all know, some aspects of this model are well-established; the exact site of the lesion, its size and etiology strongly influence the observed aphasia and its prognosis. There are few critical regions such as the posterior part of the left superior temporal region —also called Wernicke's area— whose lesions usually cause massive deficits on several language dimensions.

However, most of aphasic symptoms, such as anomia, are related to various lesion sites corresponding to a «distributed anatomy of symptoms», suggesting that a given symptom may arise from lesions localized at different points of a network distributed over the left hemisphere if not the entire brain.

Besides, the relationships between lesion anatomy and language disorders appear more stable when symptoms, rather than syndromes, such as Broca or Wernicke's aphasia, are considered.

In fact, the classical dogma on brain and language is often challenged by clinical observations that Anna Basso and co-workers (1985) called Exceptions, such as fluent aphasias with pre-rolandic lesions and vice-versa or even more paradoxical cases showing no aphasia at all despite destruction of the whole left perisylvian area, or crossed-aphasia resulting from right-sided lesions in right-handed subjects.

Many factors have been invoked to explain such exceptional cases, not really so exceptional as they were about 12 % in the Basso series.

Apart from handedness, other subject-specific factors such as age and gender may influence aphasia type and severity.

Cultural factors starting from literacy to bilingualism and familiarity with language material or language exercises are obviously major factors.

The dynamics of post-lesional phenomena should also be considered in this model, both in their neural and linguistic dimensions.

And finally, the effects of patient motivation and the influence of aphasia therapy should certainly not be overlooked.

Brain/language Relationships : Functional Imaging Data

Functional imaging techniques, and in particular PET, are potentially of great heuristic value to try to disentangle all these complex influences on the brain/language model. In particular, these techniques should, sooner or later, help us to understand more about recovery of language functions.

Indeed, aphasia should be considered not only from a negative viewpoint, as a set of deficits caused by brain lesions, but also from a positive viewpoint, as the behavioral consequences of both reorganization of neural systems and cognitive compensatory strategies.

In fact, there are different ways to use functional brain imaging to expand our knowledge beyond the limits of the classical lesion-based model.

Activation in Normal Subjects.

The first one is to address whether the regions related to impairments of specific language functions when damaged, might be activated in normal subjects during language tasks relying on the same functions.

For instance, several authors such as Geschwind (1965) or Cappa et al. (1981) claimed that phonological disorders are associated with lesions close to the left sylvian fissure whereas lexical semantic disorders are linked to lesions of regions that are more distant to the fissure, such as the inferior parts of the parietal (Brodmann area 39) or the temporal lobes (Brodmann area 37).

Using PET and a language activation experiment, we addressed (Démonet et al., 1992a, Démonet et al., 1994a, Démonet et al., 1994b) whether such a topographical segregation between phonological and lexical semantic processes might be observed in normal subjects when performing two language tasks, respectively related to each of these processes.

We used monitoring tasks with 30% targets among distractors in series of stimuli presented binaurally at a constant rate (1 per 3s); subjects responded by clicking on a button with right fingers.

In the Phoneme task, stimuli were 3- or 4-syllable non-words and the target was the phoneme /b/ if, and only if, the phoneme /d/ was detected in a preceding syllable.

For example, subjects had to detect /b/ in the non-word REDOIZABU since both /d/ and /b/ are present, but they should not click on the non-words IDOFUPO as /d/ is present but the target /b/ absent, in ZOTAFABI since the target /b/ is present but not preceded by /d/ nor in MOIGAJOPO that represents a complete distractor.

In the Word task, targets were nouns of small animals (smaller than a chicken or a cat) preceded by a «positive» adjective in adjective/noun pairs. For example, target was «kind mouse», and distractors were «superb elephant» with a positive adjective but a big animal, «bad wasp». with a small animal preceded by a negative adjective, or «horrible lion» that represents the complete distractor.

Figure 1 represents statistical maps displaying vowe in the brain in which significant changes were observed.

In the superior part of the figure, are represented blood flow increases in the semantic task compared to the phonological one and in the lower part of the figure, blood flow increases in the phonological task compared to the semantic task.

These results are in very good accord with our hypotheses based on findings in aphasic patients.

Indeed, the topography of blood flow increases matched well the distribution of lesions generating either phonemic disorders, namely regions close to the sylvian fissure or lexical semantic disorders, namely inferior temporal and inferior parietal localizations.

I would focus my talk, for few minutes, on the data of phonological processing I have just presented.

There are several PET studies on this topic that have been published in the last years —see, for example, Petersen et al. (1988), Zatorre et al. (1992), Sergent et al. (1992), Démonet et al. (1992a) and Paulesu et al. (1993)— and all the results emerging from these works confirm the importance of left perisylvian cortex in phonological processing. The relative convergence of these results should be highlighted, as such studies came from different paradigms, and different PET machines as well !

However, the experiments implicate left perisylvian areas of activation that do not strictly overlap (Figure 2). Such different results may be explained by several factors that allow us to understand better the general paradigm of language activation.

First of all, phonological processing is not a unitary psychological operation involving a single neural system, since it can be characterized as the conjunction of acoustically based processes,

articulatory based processes, sequential or global computation of phonological analysis ... and the description is not exhaustive.

Two additional, but important, factors can account for the difference:

— First, the nature of stimulation modality, either auditory or visual, of course induces activation of neural networks that differ in some aspects

— Second, the choice of the references task, *id est* the task that will be compared to the phonological condition is of crucial importance. Resting state (no stimulation, no mental activities, no motor output) so resembles «brain death condition» that it seems unrealistic. On the other hand, references task involving some cognitive processes, such as passive listening or detection of tones, may obviously obscure the activities of neural structures equally engaged in both references and phonological tasks.

Finally, two factors that are not specific to language activation have to be mentioned since they may strongly alter brain activation results.

The first one is related to the influence of stimulating conditions such as rate of presentation and exposure duration of stimuli. These factors have been recently investigated in great detail by Price et al. (1992, 1994).

For example, results from Price et al. (1992) showed that there is a linear relationship between the amount of activation in the primary auditory cortex and the increasing number of words that subjects were listening to.

Such linear relationship is not observed however in Wernicke's area which tends to respond equally to word presentation whatever the rate of presentation.

Another very important factor is related to the degree of familiarity with the task, the identification of the neural correlates of learning mechanisms during a cognitive task being obviously a crucial issue. Comparing the same language task (verb generation task) in naive and over-practiced conditions, Raichle and his co-workers (1994) demonstrated a marked influence of practice effects on the activation pattern observed with the verb generation task. The activation observed in subjects who performed a verb generation task for the first time, in particular that in the left frontal cortex, almost completely vanished after subjects had over-practiced the task and the same word list stimuli. But when another word list stimuli is presented to the same subjects, the first pattern of activation reappears.

All these factors should certainly be controlled in any activation studies and particularly in aphasic patients.

Resting State in Patients

The second way to use functional imaging and explore brain correlates of aphasia is to investigate the metabolic abnormalities that are induced by the lesions and are seen in functional images during a resting state.

A fair number of studies have been done especially in the States during the eighties. To my view, one of the major contributions of these studies was to demonstrate the existence of massive remote effects of lesions with metabolic depression spreading far away from the anatomical site of the actual lesion. The most striking example of these remote effects relates to so-called subcortical aphasia in which hypometabolism in the ipsilateral cortex is very frequently observed.

Results from one of our previous studies (Démonet et al. 1992b), based on SPECT data, highlighted examples of such remote effects with, in particular, a marked hypoperfusion in left cortical regions distant from the subcortical lesion restricted to the left striato-capsular region.

Some of these studies also reinforced the previous finding that direct or indirect damage to specific lesion such as the left posterior temporal region has a critical role in both aphasia type and prognosis.

Finally, follow up studies have been done and some others are currently reported or going on. However, these longitudinal data are still unclear, if not contradictory.

In general, the functional significance of the abnormalities or longitudinal changes in brain metabolism observed at rest remains to be clarified.

For instance, remote hypometabolic effects may represent, at least, two different phenomena.

On the one hand, the affected regions may be only de-afferented but still can participate in functional activation via other connections or networks.

On the other hand, these hypometabolic regions, particularly when they lie not too far away from the actual lesion or within the same vascular territory, may be actually affected by a neuronal loss, leading to a definitive lack of function.

Activation in Patients

The shortcomings of resting state PET studies obviously incline to explore in patients the functionality of the spared regions by using activation tasks.

This will constitute the third, and last, part of my talk.

In fact very little has been done so far using up-to-date methodological standards of PET activation that is high-resolution rCBF recordings using the O15 technique.

In Figure 3 are presented the results of one of such rare studies which was published in 1995 by Weiller et al. They studied 6 Wernicke aphasic patients with retro-rolandic lesions and a good recovery.

By comparison to the activations observed in a non-word repetition task and in a verb generation task in normal subjects, aphasics demonstrated, of course, no activation in the damaged region and increased supra-normal activations in the right hemisphere, both in the superior temporal and the inferior frontal regions and in both tasks.

Although appealing at first glance, this type of studies soon appear particularly complex because they combine two main sources of variance:

— one is related to brain lesions and aphasia, and we've already seen some of these factors in the first part of this presentation

— the other source of variance comes from the many factors that may distort the results of cognitive activation even in normal subjects.

In general, such complexity suggests that activation can only be explored on the basis of single-subject studies.

However, they are also many problems for interpreting specific activation results in such studies.

For example, a massive lesion involving a major part of the left hemisphere induced in a patient, among other language disorders, a deep dyslexia.

During a reading task in which patient performance was impaired, an activation of the right hemisphere was observed. But in fact, what else could be predicted, as only very few regions were spared in the left hemisphere.

The question of the specificity of such activations in the right hemisphere can be illustrated by data recently obtained in another patient by Walburton et al. (1996).

Figure 4 shows PET activation results co-registred with the actual MRI of this particular patient who presented a left posterior lesion.

The experimental task was verb generation on which this patient performed well. Although right hemispheric activations were seen in the verb generation minus rest comparison, these were no longer apparent in the verb generation minus listening comparison.

This implies that right-sided signals do not correspond to some sort of vicarious processes that can be involved in the verb generation task but are rather related to listening to words, a process that is common to verb generation and listening.

Thus, as the key issue of such studies is the mechanism of recovery and compensation of aphasia disorders, we are facing an even more complex problem.

We have first to specify activations in terms of

— signal localization

— task-specificity

— and time curse after lesion onset

and secondly, to establish causal relationships between functional activations and recovered performance.

Many aspects of this problem remain to be addressed in the future.

I'd like to close my talk by giving you an example of activation of a particular case of aphasia in which activation data provided some hints on the mechanisms of functional compensation in aphasia.

We studied (Cardebat et al, 1994) a case of a young man who suffered from an ischemic stoke which destroyed the left posterior sylvian region. He presented a severe Wernicke's aphasia in the first stage of evolution; after few months, he evolved towards a rare syndrome called deep dysphasia in which the main symptom is a deficit of repetition.

Repetition of concrete nouns was possible but with semantic paraphasias such as fork repeated instead of plate, whereas repetition of abstract nouns, grammatical words, and non-words was just impossible.

Auditory comprehension was quite good but again far better for concrete nouns than for abstract ones.

In general, performance on semantic tasks was fairly good but on phonological tasks, he was really poor.

The patient condition can be summarized as understanding the meaning of words (at least the meaning of concrete words) without accurate processing of their phonological forms.

We activated this patient (Figure 5), unfortunately only using SPECT but still, with, I think, interesting results.

By comparison to a references condition (listening to connected speech spoken in a foreign language), we observed activations in two tasks in which performances were very different.

During a phonological task, which was phoneme monitoring in connected French speech, patient performance was at chance level, despite increases of CBF that were seen in almost all the undamaged cerebral territories.

During a semantic task, which was monitoring for animal names in connected speech, his performance was fairly good and was specifically associated with an activation in the right posterior temporal region just as if the activation of this right-sided region could compensate for the lesion effects in a semantic task but not in a phonological task.

Whatever the technical limitations of this work, I think it shows how the combination of brain imaging methods with single-case studies of clear-cut psycholinguistic dissociations may have a major impact on the understanding of the brain correlates of language functions and dysfunctions.

In any case, this would give us the opportunity to reconcile two sometimes antagonistic approaches to cognitive neuroscience.

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Without any doubt, functional brain imaging has revealed important facts about the biological mechanisms involved in language processing. Prof. Cardebat's talk gave us an extraordinary overview of a multitude of such studies using PET and SPECT. Studies in healthy subjects revealed activation of prefrontal, inferior temporal and parietal sites during certain linguistic tasks. Language-related activation of the right hemisphere was particularly apparent in patients suffering from lesions in their left language-dominant hemisphere. All of these studies support the view that language is supported by cortical networks distributed over wide cortical areas.

Prof. Cardebat's data clearly argue against the classical view that language is processed only by two small centers in the language-dominant hemisphere. Instead, it appears that various language tasks make it necessary to activate additional brain areas, and this appears to be particularly important if part of the traditional language areas of Broca and Wernicke have been lesioned. Prof. Cardebat has even provided us with a preliminary answer to the question of what aspects of language processing may be related to the activation of which cortical regions. The left perisylvian region may support phonological processes whereas areas further away from the Sylvian fissure and, in addition, part of the right hemisphere not dominant for language, may contribute to the processing of lexical and semantic information.

Considering these results, one may be quite satisfied concluding that language processes in the brain are, by now, well understood. Let me therefore point out where present results raise additional questions and how they can possibly be attacked in future empirical research.

One of the most important findings we just heard about was differential cortical activation during phonological and lexico-semantic processing. When *nonwords* were being scanned for a particular language sound, activation was perisylvian, whereas when words of particular semantic content were detected among real *meaningful words*, activation spread to areas far away from the Sylvian fissure. Note that in these conditions both very different stimuli (words and nonwords) and very different tasks (search for sounds or meanings) were used. One may, therefore, ask whether *stimulus types* —words versus nonwords— or *tasks* —sound-related versus meaning-related— were crucial for the results. A possible next step in investigating

language processes would be to try to disentangle these factors, for example a) by presenting the same stimulus words in a phonological task and subsequently in a semantic task, or b) by presenting the different stimuli —words and nonwords— in the same task. These experiments could tell us whether the stimuli or the tasks are responsible for the differences in brain activation.

Assume that task differences were related to differential brain activation. Even in this case, a psychologist may ask which *property of the task* could be relevant. Monitoring for language sounds and for word meanings are very different tasks differing not only in what could be called general complexity, but, in addition, in the amount of attention required and in the nature of the comparison process. For example, it is usually at once clear whether a certain sound is part of a word or not. In contrast, it may in many cases be unclear whether a word belongs to a given meaning category. It is, therefore, relevant to determine which properties of experimental tasks influence brain activity patterns.

Note that also the question about stimulus differences is an important one, because there is evidence from electroencephalographic studies that words and non-words presented in the same task elicit quite different patterns of electrocortical activity (Holcomb & Neville 1990; Lutzenberger et al. 1994), and such differences have also been found in PET studies (Petersen et al. 1990). There is even evidence that very similar words —only differing in length or in their frequency of occurrence in written or spoken text— can elicit quite different patterns of brain activity (Polich & Donchin 1988; Rugg 1985). And finally, even words of different types may be processed in different brain regions (Preissl et al., 1995; Martin et al. 1996; Pulvermüller 1996). In summary, earlier results strongly suggest that both stimulus properties of verbal material and task requirements strongly affect the pattern of cortical activation. Clearly, future research addressing these questions is necessary.

A final comment I should make addresses the general question motivating Prof. Cardebat's research: It is the question of where language functions are localized in the brain. Let me stress that this question, although being a very important one, is not the only question to be addressed in cognitive neuroscience of language. An equally important question addresses dynamic properties of cortical neuronal networks processing language. Would a piece of cortex just become more active when a word is being perceived? Or would certain neurons in that piece of cortex rather exhibit a well-defined spatio-temporal pattern of activity? Is there a regular sequence of activity states that characterizes word perception and comprehension and the subsequent processes of verbal memory? Clearly, for attacking these questions imaging methods with fine-grained temporal resolution such as EEG and MEG are necessary in addition to relatively «slow» metabolic imaging techniques.

By answering questions about the cortical localization of language processes, the results reported by Prof. Cardebat clearly demonstrate that scientific work on brain mechanisms of language can be very fruitful and thereby further open a new research area. Let us hope that future research in this area will be as successful as the work just summarized.

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Recent Advances in Neurolinguistics: Agrammatism, A Case Study

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Introduction

Modern interest in the study of language and the brain emerged out of the confluence of several independent research initiatives. In linguistics, research has been dominated since the 1960s by the theory of generative grammar, originally developed by Noam Chomsky. A central tenet of Chomsky's theory is that linguistics is, in fact, a branch of theoretical biology; under this view, a theory of grammar is a theory of how the brain organizes and represents knowledge of language (e.g., Chomsky, 1965). Simultaneous with the emergence of generative grammar and quite independent of that, the American neurologist Norman Geschwind had become interested in the writings of the late 19th and early 20th century European neurologists who had studied language and the brain. Geschwind reintroduced this work and, synthesizing it, laid out a model of language organization in the brain (Geschwind, 1965). In 1967, in *Biological Foundations of Language*, Eric Lenneberg attempted to bring together what was known from neurology (including neuroanatomy) and linguistics (including psycholinguistics) to provide the basis for explorations in the biology of language. Despite the significance of the work of each of these men, through the early 1970's little systematic attention was given to neurolinguistics and only rarely were there attempts to build on this initial background (e.g., Whitaker, 1971). Suddenly, in the mid-1970s there was a burst of active research, and since then there has been a rapid proliferation of interest in studying various aspects of language and the brain.

Research on aphasia has held a central place in the development of neurolinguistics over the past two decades. From linguistics, we have the assumption that all human beings are biologically endowed with a specific capacity to acquire, know, and use a language given normal experience in a speech community; that is, there must be some biologically dedicated neural system(s) for linguistic capacity. This assumption, coupled with the consistent observation from neurology that the breakdown of language is not random, but rather has a systematic pattern, makes the study of aphasia an obvious context for investigating human linguistic capacity, in general, and language and the brain, in particular. From the onset of linguistically and

psycholinguistically based aphasia research in the mid-1970s, Broca's aphasia has been the dominant area of inquiry. This has occurred, I believe, for three pragmatic reasons: First, Broca's aphasics have, in normal discourse, relatively spared comprehension and thus, in contrast to some other populations, are fairly reliable as subjects — one need not worry inordinately whether a patient's performance on a task reflects a failure to understand the task demands themselves. Second, Broca's aphasics typically present a striking and intriguing deficit in language production, agrammatism — the systematic tendency to omit function words and omit or misuse various inflections. Finally, Broca's aphasia is a relatively common form of aphasia, so there are subjects available for research.

In this paper I will focus on studies of sentence comprehension in Broca's aphasia. In the first section, my emphasis will be on work which was carried out between the mid-1970s and mid-1980'. This work did much to establish the questions which have been of primary research interest since and, as importantly, to determine what areas would be ignored. In the second section of the paper, my emphasis will be on work done largely in the last decade. This work is striking for a number of reasons. First, unlike the majority of experimental research carried out with neurologically intact populations, a great deal of this research has been explicitly guided by linguistic theory. Second, a significant proportion of this work has been carried out with the goal of relating data on pathological processing of language to theories of the representation of linguistic capacity.

1. *What is the Domain of Study?*

In my view, two distinct avenues of investigation can be said to provide the starting point for the modern spate of activity in neurolinguistic studies of Broca's aphasia, the first being the development of awareness of a comprehension deficit and the second being the attempt to develop formal analyses of the disorder. Wernicke (1874) had observed that there were some comprehension problems associated with Broca's aphasia, but these were not considered a core or significant component of the disorder; the central deficit of Broca's aphasia was seen as lying in the domain of language production. This view was consistently maintained in neurology, psychology, and neuropsychology texts for more than a century, and, indeed, it is still found in many standard texts (e.g., Gleitman, 1995). However, in the 1970's, papers began appearing which reported a systematic comprehension deficit in Broca's aphasia (Parisi and Pizzamiglio, 1970; Lesser, 1974; Caramazza and Zurif, 1976; Heilman and Scholes, 1976; Zurif and Caramazza, 1976). The most influential of these reports (in terms of citations) were Caramazza and Zurif's (1976) and Zurif and Caramazza's (1976) papers in which it was reported that subjects with Broca's aphasia performed poorly on sentence comprehension and metalinguistic tasks with a variety of sentence types, notably reversible passive sentences. Because correct interpretation of passive sentences involves tacit cognizance of the grammatical role of function words and

inflection, findings such as these were taken as evidence that Broca's aphasia involves a parallel deficit in production and comprehension. Caramazza and Zurif hypothesized that the disruption underlying agrammatism of speech and comprehension involved an inability «to compute full syntactic representations.» This view was supported by subsequent studies of sentence understanding. While work such as that of Caramazza and Zurif was informed by psycholinguistic and linguistic concerns, that work made little attempt to provide any *formal* characterization of the impairment of Broca's aphasia; their proposal, for instance, was that patients encode semantic relations based largely on lexical content and plausibility rather than computing syntactic structure.

Kean (1977) presented the first detailed attempt at providing a formal analysis of the deficit(s) associated with Broca's aphasia. In that analysis, based on the assumption of parallel deficits in production and comprehension, the goal was to see if it was possible to account for the general range of deficit data typically ascribed to agrammatic Broca's aphasics under a single representational hypothesis. The previous research on agrammatism had provided evidence of compromises in both the syntactic and semantic analysis of sentences in the manifest performance of patients. The loci of overt deficits are not, however, necessarily the locus/loci of the underlying deficit(s) which give rise to observed behavioral limitations. The full computation of a linguistic representation involves a partially ordered set of stages. An impairment at any single stage can, in principle, lead to overt limitations in the products of other stages because well-formed inputs to the impaired level(s) of representation/processing will be distorted by the impairment(s) and the ill-formed outputs of the impaired level(s) will inevitably lead to a lack of well-formedness in the outputs of succeeding unimpaired levels. In Kean (1977) it was argued that the then known features of agrammatism could be accounted for in terms of phonological representations rather than syntactic and/or semantic representations. Specifically, it was proposed that agrammatism of speech and comprehension involve a tendency to reduce a string to the minimal sequence of well-formed phonological words. As items such as articles, non-lexical prepositions, and auxiliary verbs are not, from a grammatical perspective, independent words but rather affixes, this hypothesis predicts a tendency toward their omission. With regard to inflections, the hypothesis makes different predictions for relatively uninflected languages like English than it does for more richly inflected languages like Spanish. In the case of English, a noun stem and its minimal well-formed word are typically one and the same, e.g., *dog, house, woman*; this is also the case with verbs, e.g., *walk, eat, sleep*. In Spanish, by way of contrast, noun stems are not typically well-formed words, e.g., *perr-, cas-*, but *mujer*; verb stems, likewise, are not minimal well-formed words, e.g., *and-, com, dorm-*. It was argued that in a language such as Spanish, the minimal phonological word was typically the standard unmarked (citation) form of the item; thus, it was predicted that in agrammatism there would be a tendency toward the production of singular nouns and infinitives, e.g., *perro, casa, mujer, andar, comer, dormir*. In languages which mark case on nouns, this hypothesis predicts a tendency toward the use of the nominative singular. It was argued that if agrammatism involves the tendency to reduce

strings to sequences of minimal phonological words then it would follow that agrammatic aphasics would be unable to fully compute syntactic representations, as Zurif and Caramazza (1976) had hypothesized. While Kean (1977) was this first attempt at a formal analysis, it held a key property in common with its predecessors: Specifically, this is a descriptive analysis of the impairment and does not provide an account of the underlying source of agrammatism.

In 1983, the thesis that agrammatism might involve a parallel deficit in all facets of language use was, apparently, dealt a fatal blow by Linebarger, Schwartz, and Saffran. In their research, three agrammatic aphasic patients were asked to make grammaticality judgments. The data analysis suggested that these patients had a relatively preserved ability to make grammaticality judgments. If this were so, then it would have to follow that these patients were capable of computing syntactic structures. This is, in fact, the conclusion Linebarger, Schwartz, and Saffran draw. To account for agrammatism, they propose the «mapping hypothesis». Under this hypothesis, the deficit of Broca's aphasics involves a compromise in the mapping from well-formed and complete syntactic representations onto semantic representations —in particular, a compromise in the ability to map grammatical functions to semantic roles. Their notion of what the syntax-to-semantics mapping function is and the nature of the resulting semantic representation is, however, left undefined.

There is, however, a devastating conceptual problem with the grammaticality judgment research of Linebarger and her collaborators. It is based on the assumption that when an aphasic patient says that a grammatical sentence is indeed grammatical that they are computing the same syntactic representation of the sentence as would a normal neurologically intact individual. However, there is no basis for making such a radical assumption. Consider, for example, the sentence in (1):

1. Sally promised Mary to wash the dishes, and she did.

Two individuals could agree that this was a grammatical sentence, but from that it would not necessarily follow that they were computing the same syntactic and formal semantic representations; one of the subjects could interpret the sentence as meaning that Sally washed the dishes while the other could incorrectly interpret the sentence as meaning that Mary washed the dishes. It is only in the former case that the subject can be argued to have provided the 'correct' grammaticality judgment; in the latter case, while the judgment is apparently correct, probing demonstrates that the judgment is, in fact, not correct in the sense that the appropriate structure had been computed. Thus, to assess an individual's grammaticality judgment, one needs not only a yes/no response but also some independent data on the basis of that judgment in order to interpret the yes/no response. This is the critical issue which Linebarger and her colleagues failed to take into account.

My colleague Charlotte Koster and I carried out a judgment study in which we not only asked subjects to make judgments but also probed those judgements in order to determine their

basis, thereby overcoming the crucial problem with the Linebarger, Schwartz, and Saffran (1983) study. Our subjects included 36 healthy adults and 18 Broca's aphasics; all the subjects were native speakers of Dutch. The test consisted of 54 sentences; for each sentence, the subject had to make a judgment and then that judgment was probed. Example sentences and the probes are given in (2).

2. a. *Hans beloofde Thomas niet over zichzelf te praten*
   Hans promised Thomas not to talk about himself
   Probe: I'll let you hear it again. Pay attention ... Who will not be talked about?
   b. *Hetty overtuigde Inge een nieuwe jurk voor zichzelf te kopen*
   «Hetty convinced Inge to buy a new dress for herself»
   Probe: I'll let you hear it again. Pay attention ... Who bought a dress?

While all 36 of the control subjects provided 'correct' judgments, i.e., said that the sentences were grammatical, and 'correct' probe responses for such sentences, only 4 of the Broca's aphasics consistently provided correct judgments and correct probe responses for sentences like those in (2); the remaining 14 Broca's subjects typically judged the sentences to be grammatical but were individually inconsistent in their probe responses, sometimes identifying the correct actor and sometimes identifying the incorrect actor. Among our other findings was that all the Broca's patients were inconsistent in their judgments of the grammaticality of ungrammatical sentences both within and across types of sentence structures and of the grammaticality of certain classes of well-formed sentences (e.g., those involving nesting). Other researchers have also noted that Broca's aphasics are compromised in their abilities to make correct grammaticality judgments to some noticeable degree on some sentence types (e.g., Hagiwara, 1995; Grodzinsky, 1996). Thus, the claim that Broca's aphasics have relatively intact judgment capacities, as Linebarger, Schwartz, and Saffran (1983) argued, is not supported either conceptually or empirically. That notwithstanding, the impact of the original judgment work has been to significantly undermine the hypothesis of parallelism.

The thesis of parallelism was also dealt a blow by work which purported to show that agrammatism of speech could occur in patients with intact comprehension (Goodglass and Menn, 1985; Kegl, 1996; Kolk. van Grunsven, and Keyser 1982; Miceli, Mazzuchini, Mann and Goodglass, 1983; Friedmann and Grodzinsky, 1994, Nespoulous et al., 1984). Where there are anatomical data reported, the patients do not have a left frontal lesion as is neuroanatomically definitional of Broca's aphasia. For example, the patients reported by Kolk et al. (1982) and Kegl (1995) have parietal lobe lesions, while the CT of the patient described by Friedmann and Grodzinsky (1994) is described as «showing no signs of stroke» but «reveal[ing] an asymmetry in the size of the lateral ventricles, the left being substantially enlarged. It also shows an enlarged sylvian fissure. "Largely unnoted in the discussions of the data of Linebarger and her colleagues is the fact that the three patients they studied do not have 'classic' Broca lesions consequent to stroke. It is also significant that a number of the patients in this group of good comprehending 'agrammatics'

do not seemingly show typical agrammatic production profiles. For example, the patient discussed by Friedmann and Grodzinsky (1994), who has been extensively studied, has a highly selective deficit; her impairment is restricted to production involving (a) tense but not agreement, (b) copular constructions, and (c) realization of sentential subjects; the patient reported by Nespoulous et al. (1984) also seemingly has the same highly restricted deficit. One of the patients studied by Miceli et al. (1983) was not agrammatic in reading and was able to repeat. Thus, it is clear that some variant(s) of agrammatism of speech, but *not* comprehension or judgment, can be found in patients without Broca's lesions. What has not been shown, however, is a patient with a classical Broca's lesion (modulo considerations of depth of lesion and disconnection) who demonstrates agrammatism of speech in the absence of an impairment in comprehension and production. The data available would seem to argue that locus of lesion is a critical variable which must be taken into account if generalizations about the representation of language and the brain are to be drawn from behavioral data from aphasic patients. One cannot assume that some essentially intuitively defined phenomenon such as agrammatism is a uniform deficit across patient populations independent of locus of lesion; rather both lesion site and a constellation of symptoms seem to be critical for developing coherent and general analyses. This observation should in no way be considered surprising since it is well-attested in other areas of neuropsychology (e.g., the differences between patients with amnesia consequent to hippocampal (limbic) lesions vs. those with diencephalic lesions). If anything is surprising, it is that in the domain of aphasia research this has not been acknowledged in practice to any notable degree.

Both the grammaticality judgment research, which includes numerous papers in addition to the original work of Linebarger et al. (1983) (e.g., Wulfeck, Bates and Capasso, 1991; Shankweiler, Crain, Gorrell, and Tuller, 1989) and the reports of so-called anomalous cases of agrammatism without a comprehension deficit have had the seeming consequence of freeing investigators to focus on particular facets of disorders. In the domain of agrammatism and Broca's aphasia, the facet which has received the greatest attention is comprehension.

2. *Two Approaches to Agrammatism in Comprehension*

Given the scope of the literature now available, it is impossible to review all the proposals which have been made and received serious attention in recent years. Therefore, I will restrict my discussion here to two avenues of inquiry: studies of category processing, which initially arose out of the parallelism hypothesis, and studies of sentence comprehension. In the former case, an explicit effort has been made to account for impairments in the context of specifically proposed normal sentence processing mechanisms, while in the latter case the emphasis has been to account for comprehension impairments in the context of recent theories of grammatical representation. While the work on category processing, which has investigated the so-called open-class/closed-class distinction, might be considered a failure since it has not yielded a viable

hypothesis to account for the comprehension deficit of Agrammatic Broca's aphasics, it is a success story in that it illustrates how there can be a productive interaction between Neurolinguistics and Psycholinguistics. The work on sentence comprehension using the government-binding theory of grammar has not, on the surface, been a success either if success is solely measured on the basis of propounding a truly viable hypothesis. However, I would argue that this work has been highly successful since it represents an ongoing effort to understand the representation of language in the brain in precise representational terms.

2.1. The Open-Class/Closed-Class Distinction

That the closed-class vocabulary is somehow compromised is definitional of agrammatism; the question has always been the scope and source/cause of the compromise.

One significant line of research has focused directly on the possible processing distinction between the open- and closed-classes as superordinate syntactic categories. In 1980, Bradley, Garrett, and Zurif argued that in normal language processing two lexica are used, one restricted to closed-class items and the other encompassing all closed- and open-class items. An intuitive argument was made for postulating two lexica: The closed-class, as its name suggests, contains quite a small number of items and, therefore, can be rapidly and exhaustively searched easily; since closed-class items provide potent cues to syntactic structure, it would be an asset to an on-line processor to be able to rapidly and selectively access this part of the vocabulary. Data from normal subjects were presented to show a dissociation of vocabulary types. Based on experimental findings from aphasic subjects, Bradley and her colleagues argued that the closed-class lexical access system is compromised in agrammatism. In a wide variety of studies using both visual and auditory tasks (primarily lexical decision) there was a relatively consistent failure to replicate some or all of the findings of Bradley et al. with neurologically intact subjects and/or with Agrammatic subjects (Gordon and Caramazza, 1982, 1983, 1985; Friederici and Heeschen, 1983; Matthei and Kean, 1989; Segui, Mehler, Frauenfelder, and Morton, 1982). However, there were some partial replications (e.g., Friederici, 1985; Matthei and Kean, 1989; Shapiro and Jensen, 1986). Such work led to the proposal that the compromise of agrammatism in comprehension was not with the ability to access closed-class items, but rather with post-access processes associated with closed-class items. Most recently, this view has evolved into the notion that the underlying cause of agrammatism involves the *use* of closed class items in real time (Friederici, 1988; Garrett, 1992; Zurif, Swinney, Prather, Solomon, and Bushell, 1993; Pulvermüller, 1995; Blackwell and Bates, 1995). What is striking about all of this work is that in no case have syntactic categories been systematically contrasted in an on-line sentence processing study in which both normal and aphasic subjects participated, thus the hypotheses put forward are empirically quite tenuous.

In order to study the processing of syntactic categories, we carried out a study in which we contrasted both specific syntactic categories and the general open-/closed-class distinction. The

task selected was 'identical word monitoring', a task in which a subject hears a target word followed by a sentence in which the target word appears; the subject presses a response key as soon as he recognizes the target word in a sentence. The materials consisted of 'minimal pairs' of sentences such as those in (3), where the word in italics is the target.

3. a. *Some animals EAT* ANTS *and other kinds of insects*
Some animals EAT IN *their dens instead of in the open*

b. *Modern artists paint ON* THIN paper and fabrics
Modern artists paint ON THE *sides of buildings*

The stimuli were constructed so that each sentence pair consisted of an item where the target was an open-class word and a target where the target was a closed-class word. The open-class target categories used were Noun, Verb, and Adjective, and the closed-class target categories were Preposition, Quantifier, and Determiner. Because many verbs in Dutch do not have overt inflection in sentences, the distinction between verbs with and without overt inflection (V+ and V—, respectively) was also systematically manipulated. Each target category contrast occurred in a sentence pair in word order positions 4, 5, and 6 to control for word position effects. Furthermore, the contexts of the targets was systematically manipulated so that for half the pairs the word preceding the target was an open-class item and for the other half the preceding word was a closed-class item (e.g., EAT vs. ON in (3)). This manipulation was essential since it is well-established that in the identical word monitoring task responses to targets can be influenced by the immediately preceding word. Two such pairs were constructed for each category contrast allowed; an example from the Dutch materials used in this study is provided in (4) and (5).

4. a. *Kinderen kunnen MEER ZIEN door voor in*
Children can more see by in front of
da groep te gaan staan
the group standing
b. *Kinderen kunnen MEER DOOR hun vrienden worden beinvloed*
Children can more by their friends be influenced than you think
dan je denkt
5. a. *Leraren kunnen VEEL ZIEN in sommige oudere leerlingen*
Teachers can much see in some older students
b. *Leraren kunnen VEEL DOOR hun leerlingen worden gepest*
Teachers can much by their students be pestered

Two tapes were constructed; on one tape sentences (4a) and (5b) occurred, and on the other

sentences (4b) and (5a) occurred. Subjects were tested on two occasions, hearing one tape in the first test session and the other in the second test session. Thus, all subjects heard all 240 stimulus items as well as 60 filler items, 30 with targets in word order position 3 and 30 in word order position 7 and the targets for each position equally divided between open and closed-class items. The subjects, 36 normals, 8 Broca's aphasics, and 7 Wernicke's aphasics were all native speakers of Dutch.

In order to demonstrate that there is such a thing as an open-class/closed-class distinction which is systematically honored in language processing, it would be necessary to show that *each* closed-class item varied from *each* open-class item as well as showing that the two superordinate classes differed significantly from each other. While the latter finding was obtained for all three subject groups, there was no systematic distinction between the specific categories of the open-class and the specific categories of the closed-class for any subject population (Tables 1, 2, and 3).

	V- (263)	P (299)	Q (318)	V+ (326)	A (336)	N (337)	D (342)
V-	—	ns	ns	***	***	***	***
P		—	ns	ns	ns	***	***
Q			—	ns	ns	ns	***
V+				—	ns	ns	ns
A					—	ns	ns
N						—	ns
D							—

Table 1

Results of post hoc Newman-Kuels comparison of normal subjects' mean reaction times (in parentheses) to target categories (*** = $p < 0.01$)

	V- (408)	P (499)	Q (458)	V+ (459)	A (461)	N (444)	D (529)
V-	—	***	***	***	***	***	***
P		—	ns	ns	ns	*	***
Q			—	ns	ns	ns	***
V+				—	ns	ns	***
A					—	*	***
N							***
D							—

Table 2

Results of post-hoc Newman Kuelss comparison of Broca's aphasic subjects' mean reaction times (in parentheses) to target categories (* = $p < 0.05$; *** = $p < 0.01$)

	V- (377)	P (441)	Q (434)	V+ (420)	A (417)	N (411)	D (481)
V-	—	***	***	***	***	***	***
P		—	ns	ns	ns	ns	***
Q			—	ns	ns	ns	***
V+				—	ns	ns	***
A					—	ns	***
N						—	***
D							—

Table 3

Results of post hoc Newman Kuels comparison of Wernicke's aphasic subjects' mean reaction times (in parentheses) to target categories (*** = $p < 0.01$)

With respect to specific categories, for all populations verbs without overt inflection showed a significantly different mean response latency from inflected verbs, adjectives, nouns, and determiners, and determiners were significantly different from prepositions. That is, categories which would be expected to differ from each other under any of the versions of the open-class/closed-class processing hypotheses did not, e.g., in no population did prepositions or quantifiers differ from inflected verbs or adjectives. At the same time, categories which would *not* be anticipated to differ from each other did, e.g., in all populations verbs without overt inflection differed from all the other open-class categories, and, also for all populations, determiners differed from at least one of the closed-class categories. These findings support the notion that the so-called open-class/closed-class distinction is an artifact of summing across categories. While the patients had slower reaction times than the normal subjects, globally their performance showed the same pattern as that encountered with normals.

In order to further investigate the data for evidence of the open-class/closed-class distinction, the patients' error data were considered. There was no difference between the two aphasic populations in terms of error rate, and the pattern of errors was the same for both groups, e.g., among the Broca's there were 11 failures to respond to Adjectives, 24 failures to respond to uninflected verbs, and 25 failures to respond to Quantifiers, while the Wernicke's had 15, 23, and 24 failures to respond on these categories, respectively. Both patient groups showed significantly more errors with the closed-class categories than with the open-class categories, but this can be attributed to the comparably high rate of failure to respond to determiners by both groups of aphasics. Thus, when the open-class/closed-class distinction is investigated in detail one finds that not only is there an absence of evidence supporting its role in normal processing but there is also an absence of evidence supporting its role in distinguishing Broca's aphasics from Wernicke's aphasics in sentence comprehension.

In recent work a new approach to the open-class/closed-class distinction can be found in work which distinguishes functional categories from lexical categories and their syntactic projections. Both Hagiwara (1995) and Friedmann and Grodzinsky (1994) have taken this approach. While the cases they discuss are restricted, the general idea bears consideration. Put generally, the idea would be that Agrammatic aphasics have a deficit with respect to functor or specifier categories; in any structure where one of these categories appears, all nodes above it are defective. One consequence of such an approach is that it predicts that there will be impairments in sentence processing for sentences in which anomalous performance is not overtly the result of problems with some specific closed-class item(s). This is a line of conjecture which is potentially promising for the analysis of both normal and impaired sentence processing.

2.2. Government-Binding approaches to agrammatism

Since the mid-1980's, a major avenue of research into the study of agrammatism has been syntactic analyses of so-called 'Agrammatic comprehension' carried out within the government-

binding grammatical framework. In this work 'Agrammatic comprehension' refers not just to comprehension problems which are directly attributable to the closed-class, but rather to the comprehension deficits of patients whose speech is Agrammatic and who exhibit the following performance constellation on comprehension tasks.

(6) Chance Level Performance
a. Center-Embedded Object Relatives (Caramazza and Zurif, 1976):
The dog that the horse is kicking is brown
b. Reversible Syntactic Passives (Schwartz, Saffran, and Marin, 1980):
The boy is chased by the girl
c. Right-Branching Object Relatives (Grodzinsky, 1984):
Show me the boy that the girl pushed
d. Object Clefts (Caplan and Futter, 1986):
It was the horse that the dog chased

(7) Above Chance Performance
a. Center-Embedded Subject Relatives (Grodzinsky, 1984):
The horse that is kicking the dog is brown
b. Reversible Active Sentences ((Schwartz, Saffran, and Marin, 1980):
The boy chased the girl
c. Right-Branching Subject Relatives (Grodzinsky, 1984):
Show me the boy that the girl is pushing
d. Subject Clefts (Caplan and Futter, 1986):
It was the horse that chased the dog

A variety of proposals have been put forward to account for this range of data, just a few of which that are closely related will be considered here to illustrate how vibrant this line of research has become.

Grodzinsky's (1986a,b) Trace Deletion Hypothesis (TDH) provided one of the first attempts to account for the pattern of Agrammatic comprehension, (6) and (7), within the framework of Chomsky (1981). His basic observation was that comprehension is seemingly impaired where there is movement from object position but not when there is movement from subject position. In the normal case, where there is movement, a trace of the moved element remains at its original locus, and this trace and the moved element are co-indexed. Theta-roles (e.g., AGENT, THEME) assignment is mediated by a chain between the trace and the moved element. In Agrammatic comprehension, Grodzinsky argued, the trace is deleted or invisible, and it is, therefore, impossible for the moved element to be assigned a theta-role via the chain. Chance performance on sentences such as those in (6) arises because, when an item is not assigned a theta-role, the Default Principle (8), takes over.

8) The Default Principle

An NP which is not assigned a thematic role...should be assigned a theta-role according to a *list* which universally associates default values with positions.
[Grodzinsky, 1986a, p. 145]

This principle, which is not developed on the basis of linguistic considerations but rather through experience, will assign an agent role to clause initial nouns in English. Thus, in a sentence such as *The dog that the horse is kicking is brown* both *dog* and *horse* will be assigned AGENT, which is the source of the chance performance on such sentences. As has frequently been observed, a central problem with this proposal is that the Default Principle is ad hoc —not based on any established psychological or psycholinguistic principles of strategies— and consequently difficult to evaluate.

Hickok (1992) observes that there are aspects of Agrammatic comprehension which Grodzinsky's TDH cannot account for: (a) Hickok and his colleagues found that for sentences such as *The tiger that chased the lion is big* comprehension performance of agrammatics was below chance even though there is mediating between the subject and matrix predicate. (b) Caplan and Futter (1986) and Caplan and Hildebrandt (1988) observed chance level performance with two verb subject-relative constructions, e.g., *The horse that chased the cow kicked the pig.* And, (c) Caplan and Hildebrandt (1988) and Grodzinsky and his colleagues (reported in Grodzinsky, 1990) reported chance level performance on simple sentences with pronouns like *The girl pushed her.* To account for these data as well as those in (6) and (7), Hickok proposes the Revised Trace Deletion Hypothesis (RTDH) in which it is also claimed that traces are deleted or inaccessible.

The RTDH is based on the syntactic assumption of the VP-Internal Subject Hypothesis under which subjects are based generated in the Spec of VP, where they receive there theta-role, and then move to Spec of IP to receive Case at S-Structure. Hickok's analysis also, crucially, makes use of the thematic assignment representation of a verb; this representation is of the form «Verb (x (y))», where x denotes the external argument of the verb and y the internal one (Williams, 1981; Grimshaw, 1990), and unspecified arguments are denoted *. For example, the thematic representation assignment for *The girl chased the boy*, [$_{IP}$ The girl [$_{VP}$ * chased the boy] would be *chase (* (boy)); girl.* Hickok proposes that it is just such representations which are available to the general cognitive system. In sentences such as those in (7), where performance is above chance, an internal argument is specified and only one NP is left to be interpreted as the agent. In contrast, for sentences such as those in (6 a, b, and d), there is more than one NP available for interpretation as the unspecified arguments leading to indeterminacy, hence chance performance. Having thus accounted for the basic cases, the RTDH also provides a fairly straightforward analysis for the other cases of chance performance at issue. There are two features of note in the RTDH: First, it provides an analysis of a wider range of data than does the original TDH. Second, it does not require resort to an ad hoc strategy such as the Default

Principle. A serious weakness of the RTDH, as well as the TDH, is that neither can account for cases of performance which is below chance as has been reported by Grodzinsky et al. (1988) with passives of psych verbs, e.g., *The man is adored by the woman.*

The only data considered in both Grodzinsky's original TDH and Hickok's RTDH involve NP movement. If some variant of either general theory were correct, then it would be expected that Agrammatic aphasics would have difficulties in comprehension with sentences which involve verb movement. However, Lonzi and Luzzatti (1993) have suggested that agrammatics are not impaired in processing sentences with verb movement. To address this finding, Grodzinsky (1995) proposes that only traces in theta-positions are deleted (or invisible) in Agrammatic sentence representations. At the same time, he restricts the Default Principle, proposing a variant, the R(eferential) Strategy, which assigns a referential NP a theta-role «by its linear position» just in case it has no theta-role. The R Strategy is claimed to be a non-linguistic strategy which does not apply to non-referential NP's. However, if the R Strategy is a non-linguistic strategy, how can it critically be sensitive to a specific linguistic distinction, that between referential and non-referential elements.

The issue of referentiality has emerged in recent years as a key topic in the analysis of agrammatic comprehension. To take one example, Avrutin and Hickok (1992) engage this topic through consideration of *Which*-N questions, involving subject and object extraction (9), *Who* questions, which involve a bare wh-operator (10).

9. *Which horse chased the giraffe?* (subject extraction)
   Which horse did the giraffe chase? (object extraction)
10. *Who chased the giraffe?* (subject extraction)
    Who did the giraffe chase? (object extraction)

The account they propose is based on the linguistic distinction between *binding* and *government*. Binding relations are generally unbounded and formed by the movement of a referential element, while government relations are bounded by locality principles and arise from movement of non-referential elements (Rizzi, 1990). Building on this, Cinque (1990) proposes that *which*-NP head binding chains while bare wh-operators head government chains. Avrutin and Hickok (1992) presented actions scenarios to Agrammatic patients and then asked either a *which*-NP or *who* question. Performance on subject extracted NP's for *which questions* was above chance, while performance on object extraction *which* questions was at chance. For both subject and object extraction *who* questions, performance was above chance. To account for these data, they propose that the deficit of agrammatism involves binding chains but not government chains; the asymmetry with *which* questions is explained by the preservation of government chains. [See also, Hickok and Avrutin, 1995.] As Grodzinsky (1995) has observed, this account seems to fail to account for the passive data since passives do not involve binding chains in Cinque's theory. Another problem with this analysis is that it seemingly predicts above

chance performance with object clefts and object relatives, which is contrary to the observations of Agrammatic comprehension.

What is striking about this line of research is its overwhelming success in invigorating research on agrammatism and bringing detailed and current linguistic theory to bear on the analysis of agrammatism. Such research illustrates how far we have come since the work of Caramazza and Zurif in 1976; at that point it was a breakthrough to observe simply that agrammatics had a problem in computing syntactic representations. Because of the detail of the hypotheses being put forward, they are easily falsified, but, more importantly, they suggest new areas of investigation. Beyond that, this research raises significant questions about the mechanisms of normal processing. For example, one of the conjectures of Avruten and Hickok (1992) is that there are differential processing mechanisms for binding and government chains with binding chains demanding more processing resources because they involve potentially unbounded relations. In this, neurolinguistic research is posing a significant question for the understanding of normal sentence processing.

3. *What's Next?*

It is clear that the burst of research activity which was set off following the work of Caramazza and Zurif has been highly productive. Not only do we now know that there is a comprehension deficit associated with agrammatism, but the details of that deficit are only beginning to be understood. It is clear that this approach will continue to be fruitful. However, there are two serious weaknesses with the work that is being done that need to be addressed in the future. First, while there have been great advances in the study of comprehension, there has been relatively little research on production. Agrammatic Broca's aphasics have both production and comprehension deficits and both facets of the disorder demand exploration. The hypothesis of parallelism has been abandoned for no empirical reason, rather it has simply become irrelevant to most investigators. Whether or not there is parallelism —or even partial parallelism— has major implications for our understanding of the structure of normal linguistic capacity. Aphasia research offers a unique window on both representation and computation in production and comprehension which it is a mistake to ignore. Second, despite the wealth of available data and the implications of the analyses of those data for theories of normal processing, there has as yet been relatively little attempt to connect hypotheses related to Agrammatic deficit to explicit theories of computational processes for normal representation. It will only be when approaches to normal processing in adults show the same vigor and attention to linguistic detail as aphasiological research as work such as that described here that neurolinguistic research will make the contribution, which is its potential, to our understanding of the organization of linguistic capacity. Thus, there are important areas which we have yet to provide sufficient attention to.

The advent of imaging technologies and their increasing availability for research will provide us with a new means of assessing the organization of language in the brain. As viable techniques are developed for exploiting imaging technologies to investigate questions of detail and subtlety in syntax, studies with both normal and aphasic subjects will give us a new window on the representation of language in the brain. Where those investigations will lead us is unknown, but it is certain that the excitement of the past two decades will come to pale by comparison.

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The two comments I would make in response to the lecture of M.L. Kean are from a neuropsycholinguist not specialized in the field of agrammatism. The first part will come from the neuro side while the second originates from the psycho side of mind/brain science.

Let me begin with the neuro side of my comments.

The arguments developed by M.L. Kean are mainly linguistic. Nevertheless, she agreed with the importance of lesion sites to incorporate agrammatism's theory in brain. I would present some results on this topic arising from two studies, the first one reporting lesion sites on CT scans in Agrammatic patients, the second one reporting functional data by PET in normal subjects.

In a cross-linguistic study, Menn and Obler (1990) presented 28 Agrammatic patients defined according to Goodglass's criteria, namely reduced phrase length and omissions and/or substitutions in their productions yielding a telegraphic style.

The lesions revealed by available CT scans of 20 patients reveal a wide variety of sites. Agrammatism can follow lesions which virtually destroy the cortex and the subcortex supplied by the middle cerebral artery or its branches. Hence, lesions of any part of the classical language area in various combinations may be associated with agrammatism.

Moreover, small lesions can also cause agrammatism. As far as can be seen from the data available, these smaller lesions can affect parts of the traditional Broca's area —the pars opercularis and triangularis of the third frontal convolution— and the pre- and post- central gyri, the insula, and cortex restricted to temporal/parietal lobes. These last results are immediately consistent with the possiblity that the language-processing functions which are disturbed to yield agrammatism can be narrowly localised ... but this narrow localization may concern the entirety of the perisylvian cortex including the insula.

However, all these lesions shared a common anatomical site that was found to be localized in the insula and the arcuate fasciculus, so that, another possibility is that it is a lesion in one or both of these structures which is responsible for agrammatism.

Finally, the more traditional view, that the set of symptoms known as agrammatism is narrowly and invariantly associated with a lesion in Broca's area or in the opercular part of the precentral gyrus do not receive direct and strong support from the present CT data.

Thus, correlations between lesion sites and agrammatism as an aphasic syndrome appear quite unsatisfactory. It may be more interesting to rather consider particular patterns of agrammatism, for example, Agrammatic output associated with intact comprehension. In the 3 cases observed in Menn & Obler's series with this particular feature, lesions always spared Broca's area and were mainly localized in temporal parietal regions.

It might be therefore that, quite at variance with classical views, the role of Broca's area (or, at least, parts of this region) is related to syntactic comprehension rather than to language output programming.

A strict one-to-one relationship between lesion and symptom is unlikely anyway, and functional brain imaging might contribute to disentangle such complex issues as it provides information independent of the aphasiological model.

Recently, PET has been used to investigate the regional brain activity associated with sentence-level language processing, see for example Mazoyer and colleagues (1993), Bookheimer and colleagues (1993) and Stromswold and colleagues (1996).

The study of Stromswold et al. seems to me particularly interesting since its title is «Localization of syntactic comprehension by PET». The authors aimed at determining regional cerebral blood flow when 8 normal right-handed subjects read and made acceptability judgments about sentences.

Three conditions were used:

— in the first condition, sentences contained center-embedded relative clauses and,

— in the second condition, sentences contained right-branching relative clauses.

Half of the sentences in conditions 1 and 2 were semantically plausible and half semantically implausible.

— In the third condition, that was a control condition, half of the sentences were exactly the same as the plausible center-embedded and right-branching relative clauses and the other half were unacceptable because one of the nouns or verbs had been replaced with an orthographically and phonetically pseudoword.

The main result concerns rCBF increase in Broca's area (particularly in the pars triangularis) when subjects assessed the semantic plausibility of syntactically more complex sentences, namely center-embedded relative clauses, as compared to syntactically less complex sentences, namely right-branching relative clauses.

These results provide evidence supporting the role of a portion of Broca's area in the assignment of syntactic structure in sentence comprehension.

In their discussion, the authors argue that the increase in rCBF found in Broca's area may reflect changes in neuronal activity associated with a greater memory load for processing center-embedded relative clauses.

This interpretation of syntactic activation study in terms of memory load offers me the opportunity to move on to my second comment.

Indeed, the understanding of agrammatism should include psycholinguistic dimensions, especially attentional and memory processes.

In particular, not only has the role of the memory to be considered but also it should be tested in a systematic way. For instance, the understanding of center-embedded relative clauses, may induce an increase in the activity of verbal working memory. More precisely, the involvement of verbal working memory could implicate the activation of either rehearsal processes or phonological storage, processes that can be selectively disturbed in some patients.

For example, one of our colleagues, Jean-Luc Nespoulous (1988) described a few years ago a patient, Mr Clermont, with agrammatism without comprehension deficit. In this patient, the reading performance was far better than the repetition performance for exactly the same sentences. This feature could be explained by a deficit of the articulatory loop.

In conclusion, I think a comprehensive approach to agrammatism has to be threefold, combining linguistic theories, psycholinguistic analysis and functional neuroimaging studies.

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Language in Dementia: Implications for Neurolinguistic Theory

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Introduction

For a generalist audience, it is worthwhile to define dementia and discuss the phenomenology of language changes associated with it before turning to the theoretical issues of interest. Thus I will start this presentation with a discussion of dementia broadly, then narrow in on the type of dementia of that is of greatest interest for those interested in language, Alzheimer's dementia. Then I will describe the language changes associated with its various stages. In the second part of the paper, I will focus on four areas of theoretical interest: **first** the interaction between language and cognition that is revealed by the language changes of dementia, particularly as these can be compared to the language changes associated with frank brain damage such as in aphasia resulting from stroke or brain trauma; **secondly**, the related question of whether, underlying the language changes of Alzheimer's dementia is an actual dissolution of the semantic store, or rather problems with access to it; and **thirdly**, what we learn from bilinguals who are demented about the pragmatic and underlying cognitive abilities associated with bilingualism.

Definition of Dementia

Neurologists define dementia as being a disease state resulting from cellular changes in the brain whereby cognitive abilities are progressively impaired. Three out of the following four characteristics must occur in order for dementia to be recognized: **one**, changes in language; **two**, changes in memory; **three**, behavioral changes, such as markedly increased irritability or belligerence or, in one case I know of, a disconcerting increase in «niceness» in someone who had previously always been quite critical; and **four**, impairment of manipulation of acquired knowledge; the standard test for this is the ability to, say, recite the alphabet backwards, or spell a word such as «world» backwards.

There are a number of different sorts of dementia and they occur with relatively different frequency in the general population. Some of them are considered to be the result of primarily subcortical damage, that is, damage to the interior areas of the brain, while others are considered to be the result of damage primarily to the cortex, that is damage to the external surface, its convolutions and gyri, of the surface of the brain. I'm not going to talk about the primarily subcortical dementias, but for your information they include diseases like Parkinson's Disease and Progressive Supranuclear Palsy. The primarily cortical dementias include Pick's Disease which is associated with cellular damage primarily in the frontal lobes of the brain, and, my focus for today because the language changes are so interesting, Alzheimer's Disease which is associated with cellular changes both in frontal lobes and in temporal lobes of the brain.

For our purposes here, we don't need to discuss the specific cellular and, presumably neurochemical changes that are associated with the dementias; it is the behavioral phenomena that are of interest to us.

One of the forefathers of modern neurolinguistics, Carl Wernicke, in his famous 1874 article in which he described the fluent aphasia of Wernicke's aphasics, was the first to point us to a case of Alzheimer's Disease. It is worth reminding ourselves how Wernicke's Aphasia manifests because in certain stages towards the middle of the decline of Alzheimer's Disease, the language is quite similar to it. In the Wernicke's aphasic, whose lesion is associated with brain damage to the posterior part of the language area of the brain, the production of language is quite fluent — unlike that of the non-fluent Broca's aphasics who had been described a decade before by Paul Broca — but, again unlike the Broca's aphasics, comprehension is quite poor. When Wernicke talked about these cases, he gave two examples. The first is clearly the case of a patient who had suffered the sudden onset that is typical of the aphasias and Wernicke dealt with this patient at length; the second case he brings in to bolster his argument that the phenomenon is a more general one; this case is actually, upon careful reading (as in Mathews, Obler and Albert, 1994) more likely a case of Alzheimer's dementia, as the decline was progressive.

Alois Alzheimer himself published two important papers on the dementing disease that was to be named after him, one in 1907 and one in 1911. In addition to careful analysis of the cellular changes associated with the atrophy in the brains of patients he had seen before they died, Alzheimer includes superb descriptions of the language changes and other behavioral changes associated with what we have come to know as Alzheimer's dementia. It was his clinical observation that in the demented patient one sees impairment in the ability to name things, the ability to comprehend what is said to the patient, the ability to read and write. In the modern period we have understood that the ability to read aloud is markedly better spared than other language abilities, that repetition may be relatively spared, and that automatic speech shows some decline as well. Problems with discourse are seen in that while a substantial amount of language may be produced, it is quite empty and often impossible for the listener to make sense of.

In the modern period, also, we have come to have an understanding of the stages of dissolution. For the purposes of this presentation, I will speak about three stages: early, middle,

and late, although it is often of interest to focus on the stages between early stages and mid-stage and between mid-stage and late stage.

In the **early** stages naming is most likely to be impaired, comprehension in normal conversation appears to be relatively spared, in discourse the patient may wander from what he's said, or not respond fully to what he's been asked, but conversation can still go on. Reading aloud is quite spared, though reading for comprehension of any complex materials poses some problems.

The patient can still write and his speech will be as meaningful as his oral presentation. Automatic speech is relatively spared, although the patient may skip a month of the year in reciting the months of the year, for example, or need to be given the first month in order to start reciting the months of the year.

In addition to the language changes, clinically the patients' family will complain about their behavior in the real world: perhaps they are no longer able to appropriately use a checkbook, or will leave food cooking on the stove or leave crucial ingredients out of a recipe. Patients' memory problems will also become quite severe; they may become lost a few blocks from their house, forgetting where they standardly keep keys, etc.

By the peak of the **middle** stages of the disease, the patient looks like a classic Wernicke's aphasic. On naming tasks, the patient can name only the most common items, but he or she will come up with interesting substitutions for names; these may include examples of visual misperception e.g. **cucumber** for **escalator** or semantically related items (e.g. **elevator** for **escalator).** The patient's comprehension is as poor as that of a Wernicke's aphasic, so if patients respond to some association to a single word in a question, that is not surprising. While most reading aloud may be spared, for languages like English that have many irregularly spelled words, the patient may regularize these, for example pronouncing the word «yacht» as /yatcht/. In writing there are numbers of misspellings and omitted words, as well as nonsense words. Such nonsense occurs in discourse as well; indeed discourse is quite empty as you see in the transcription. The patient is unlikely to complete items of automatic speech as well and cannot perform on metalinguistic tasks.

PATIENT 3

E: How old are you?

HJ: I Know I'm a 1937. Well... I tell you what. I have more than for that matter... Germany... eh like, for instance, I'm supposed to be in one and my, my wife is another one. She she's happened in another one. She, she —it takes her that way. See? Because she's in two places, you see, in other wo— she's she is a German, for one thing. And I'm Henry. I'm Josi, Josi, you know... that's what...

E: O.K. Let me ask you once more. How old are you?

HJ: At this moment, if you wanted if I should say... that I'm, I'm gonna do... Jesus! I could have...

E: Well let me ask you a different way.

HJ: When I'm fifty... I was gonna sixteen, no... well, I'm... Oh God.

E: Let me ask a different way. When were you born?

HJ: 19... A long time ago you wouldn't even know what it is that's a don't... that's an American cos (?) That's another thing. See? That's another one... in other words when I came, when I come s-and the time... and it goes —be it foreman and what have you, you know... and go to Germany. That'sd be something else. You see? That's my...

E: O.K. Let me ask you one more question. What year is it now?

Pragmatic abilities are often remarkably spared, however. The patients can be interrupted in their logorrheic outpouring and will respond to questions even if the response does not make sense in light of the question (or independently!). By this stage the patient requires substantial home care — a classic book on how the caregivers' feel is entitled «The 36-hour day»— and they are no longer able to undertake all but the simplest activities from their pre-morbid life.

In the late stages of the Alzheimer's dementia, language is virtually nonexistent. The patient initiates little speech, may respond pragmatically with a formula, or keep eye contact, but has no sophisticated pragmatic abilities left, and really cannot be tested by any standard language tests. Such patients are frequently institutionalized in the United States.

Now that you have a picture of how the language of a patient with Alzheimer's Disease is likely to look across the progression of the disease, let me turn to the theoretical questions that are raised by patients with the disease. Let us consider first the relation between language and cognition. Carl Wernicke himself had already called attention to the potential link between language and cognition in his classic 1874 article but his position was that the two can be separable. Indeed, he was right in that in aphasia, on which he intended to focus his discussion, they are. Alois Alzheimer, by contrast, saw «aphasia» —that is language problems associated with brain damage— as being one of the behavioral components of Alzheimer's disease.

Consider the problems posed by the phenomena of Alzheimer's Dementia for modern linguists or neurolinguists: We are interested in studying the brain bases of language, and many of us are committed to a belief that a certain subsection of the brain is associated primarily with language, although many other parts may be involved as well. We are committed, too, to a belief that language and cognition are independent. While in aphasia it is often possible to demonstrate that patients have understood, or can problem-solve, even if they cannot articulate an answer, in dementia the language and cognitive problems are clearly confounded with each other. Most overtly, if a patient has difficulty with remembering the name of an item, or calls it «thing» or substitutes another word for it altogether, can we say that the problem is strictly a language problem, or is it conceivable that it is another aspect of the many memory problems the patient has? When the patient presents empty discourse, is it because the patient isn't thinking of content to express, or is the thought in fact there, but the ability to articulate it is impaired?

When the patient has difficulty comprehending us, how can we know if this is strictly a linguistic problem, or a problem of memory, or manipulating acquired knowledge, or attending to the materials (one often finds attention problems in patients with Alzheimer's dementia or other dementias) or problems with working memory or short-term memory? In sum, it is when the language problems co-occur with the dementia that we cannot be sure if they are primary phenomena of language impairment or linguistic epiphenomena.

To resolve these questions from the data from Alzheimer's dementia, it is important to recall the aspects of language that are relatively spared. Thus it is clear that **syntax** remains quite unimpaired in production for patients with Alzheimer's disease as for those with Wernicke's aphasia. **Phonology,** too, and **morphophonological** rules are quite spared. Thus the patient will not show the problems that a non-fluent aphasic may show of distortion of phonemes. Although the patients do produce nonsense words —we call these **neologisms**— they would never create words that are **structurally** impermissible in a language, either in terms of the phonemes that are permitted to follow each other, or in terms of the morphemes that are permitted to follow each other. These sparings hold, I must point out, even in that florid middle stage when the patient may produce empty speech, even virtual nonsense. To the extent that these items are spared, of course, we must consider that the other language problems reflect a cognitive decline independent of linguistic abilities.

The second question I promised to treat, is whether the language problems are primarily problems of access to the linguistic store or dissolution of it. This question has been a focus of many researchers over the past decade. It is closely linked to the first question, as you will see. I mentioned earlier that one question we ask when patients are unable to name an item that they see or see a picture of, is whether this is a language or a memory problem. Many psychologists do not see a frank difference between them. They talk about the «semantics store» which includes, as far as I can tell, all language components, including words, as well as all the rest of

the knowledge we have learned in our life - e.g. the fact that New Year's Day is January 1st or how to get to this conference room. In Alzheimer's Disease, when patients are unable to read irregularly spelled words that we know they must have read relatively automatically before the Alzheimer's disease, or when they are no longer able to produce automatic speech in its entirety, we begin to suspect that the problem is frank dissolution of the semantic store. One important cue lies in the consistency of the response. If the patient is consistently unable to name a certain item, we may suspect that that item itself is impaired. Myrna Schwartz and her colleagues report a patient named WLP who was no longer able reliably to name common items, and was not even able to reliably sort pictures of dogs, cats, and birds into three piles. However, it is important to note that while the patient often sorted dogs and cats into the same piles, she never confused them with birds. Thus we may say there was **some** dissolution of her semantic categorization abilities, but not complete dissolution, obviously. The more superordinate category, bird vs. four-legged pet, was retained.

We recently conducted a study because patients with Alzheimer's dementia are observed to produce some neologisms - that is, nonexistent words, in their discourse, and also are observed to make semantically-related errors on naming tasks as well as in discourse (Nicholas et al., 1996). It was our hypothesis that patients with Alzheimer's disease, when they made semantically-related errors, would manifest errors that were semantically more distant from the target items than were such semantically-related errors that can also be made, albeit to a lesser extent, by normal elderly. First we had raters exclude patients' responses that represented visual misperceptions. In fact it is the case that patients with Alzheimer's dementia make markedly more of these than normal elderly individuals. Then when we had the remaining responses that could be deemed to be semantically-related responses, we had another set of raters rate the semantic distance of each error item from the target. We expected that, as I said, the semantic distance of the semantically-related errors of the Alzheimer's patients would be greater than that of the normals, and thus reflect the dissolution of the actual semantic store. For example, we expected more close errors like **elevator** for the target **escalator** from the normal elderly and more distant errors, such as **seal** for **beaver** or **hot dogs** for **pretzel** from the patients with mild-to-moderate Alzheimer's Dementia. To our surprise, there was no difference, nor even a tendency in the direction we anticipated. This then suggests that the semantic networks of the patients with Alzheimer's disease are as spared as those of normal elderly, and the problem on the naming task, markedly more severe for even these moderately demented patients, of course, is a problem of lexical access.

Another study that suggested that semantic organization is intact in Alzheimer's Dementia, while conscious access to it is impaired, by contrast, is a series of studies by Nebes and his colleagues (Nebes, Martin, and Horn, 1984; Nebes 1989; Nebes and Brady, 1988; 1990). Moreover the tasks they used were on-line tasks of semantic processing. Because these tests of semantic processing are on-line tasks, they eliminate the memory and other language production problems in the studies that are consistent with decline in the semantic organization

itself. In those studies, then, problems with the additional memory load may be falsely suggesting problems in semantic store.

However there is also data in the literature that suggests impairment in the actual semantic store. Studies of consistency in naming also speak to the question of whether the lexical store is impaired or simply hard to access in Alzheimer's Disease. Of course, virtually all neurobehavioral performance in patients with Alzheimer's disease is markedly more variable from day to day, even from minute to minute than in aphasics, who themselves perform somewhat more variably than normal elderly. Normal elderly themselves perform more variably than normal young subjects on many neurobehavioral measures. When consistency scores on naming batteries are studied, as in Henderson, et al., 1990, we see a certain consistency of naming errors that suggests that actual items have been erased or conflated with others in the lexicon, and thus that semantic memory itself is impaired.

In a recent study by Hodges and colleagues (1996), the authors ask patients with dementia and normal age-matched controls to give oral definitions of words that the patient has been able to name on a picture-naming task and also words that the patient was not able to name. Even for items they were able to name, the patients with Alzheimer's Disease gave worse definitions, and for the items they were not able to name, patients with Alzheimer's Dementia were unlikely to be able to provide even core concepts, although they were able to describe physical aspects of the object. This led the researchers to conclude that the problem in Alzheimer's Dementia is one of dissolution of the semantic store, although of course the problem is that they evaluated their subjects' oral definitions and thus compounded whatever definition problems the subjects might have with the problems of lexical access in discourse!

The question then, of whether it is access or dissolution that accounts for the language problems we see in patients with Alzheimer's dementia, remains unresolved. It certainly may be that there are both aspects of dissolution and of problematic access, but further work in many linguistic arenas remains to be done to determine the complex answer to this question.

The final point I want to cover here is the question of what happens in the bilingual demented patient and what it means. If language stores and the boundaries among items in them dissolve, one might expect bilingual patients with Alzheimer's disease to mix languages at every level, from phonological through morphological, syntactic, and at the discourse level. In fact, to one's surprise, there is relatively little intermixing. Some patients do show the sort of mixing that we can sometimes see in aphasic bilinguals, although there too, the normal bilingual's ability to keep two languages quite separate for production is remarkably spared. Instead of seeing such mixing on a large scale, except perhaps to borrow words in when the appropriate word cannot be found in discourse in the relatively early stages of dementia, the interesting phenomenon one sees in bilingual dementia is an inability to appropriately choose the language according to the interlocutor. A number of instances have been reported in the laboratory of Kenneth Hyltenstam and Christopher Stroud, my laboratory, and those of others, where bilingual demented patients will speak a language that the interlocutor does not understand. Usually this is an immigrant

grandparent, say, speaking the first language to a grandchild or to a health care practitioner who simply does not understand it.

Now this phenomenon is an interesting one because we do not see such «regression» to the first language in aphasic patients. The aphasic bilingual patient, while often able to speak —albeit aphasically— in impaired fashion in both languages proportional to how they were known before the aphasia-producing accident, will sometimes recover one or the other language disproportionally to how it was known before, as Michel Paradis discusses in this conference. In the latter cases, even when one language recovers disproportionally well, it is most frequently the language the patient has been using around the time of the accident, and thus, usually, the appropriate one in the environment the patients find themselves in. With the demented patient, as you will have understood, the opposite is the case. Here we often see the «regression» to the first language that Ribot posited would obtain (although it only obtains with chance frequency - Obler and Albert, 1977) in the bilingual aphasic, where the first-learned language should be better spared.

What is of theoretical import from this phenomenon is the bolstering of the notion with respect to bilingualism in normal individuals that from a very early age - I've seen it at two myself and it's usually reported from three - the child has developed a system for keeping the two languages separate for production and, moreover, the children are quite sensitive about figuring out with whom they speak. With bilinguals, the healthy bilingual child or adult may, in culturally appropriate instances, code-switch between the two languages; with monolingual speakers of either or any of their languages, they will appropriately restrict themselves to that language. It is **this** ability that appears to break down in dementia, and as is so often the case in neurolinguistics, it is precisely from the systematic breakdown that we learn about the modularity of abilities in normals. Clearly there is a component of normal bilingualism that consists in assessing the interlocutor's language abilities (and tolerance for code-switching) and determining which language to speak. It is this particular ability, then, that breaks down in discourse of bilingual patients with Alzheimer's Disease, on top of the other problems we have discussed earlier.

To conclude, then, we have evidence that certain aspects of language are remarkably spared in Alzheimer's Dementia as long as speech is produced. These are phonology, morphology, morphophonology, and even syntax. Thus language itself can be seen, even in dementia, to be relatively independent of other forms of cognition. The most problematic intersection of the two is in the lexicon or semantic memory. Here the question is unresolved as to the independence of the linguistic elements from the other data on both sides of the question at this point. Pragmatics too is a point of interesting interface. In the monolingual, as in the bilingual, we see certain aspects of pragmatics relatively spared into the late stages of the disease (Causino, et al., 1994). In the bilingual, one crucial aspect of pragmatic competence is impaired, namely the ability to appropriately assess what language or combination of languages the interlocutor expects to hear.

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Dr. Obler discussed three questions. I shall address each one in turn. With respect to the first question, we should not be surprised that language deficits in patients with dementia of the Alzheimer type should be similar to those of patients with aphasia, or, for that matter, to those of normally aging individuals, or to those occurring occasionally in young, perfectly healthy individuals under stress, fatigue, or after one too many martinis. It is captured by the corollary to Murphy's Law, according to which only what can go wrong will go wrong —and only in the specific ways allowed by the structure of the system— here, the language system. Differences may be quantitative: patients with dementia of the Alzheimer type will progressively make more errors, and errors of a particular type, depending on which cortical area happens to be affected, and correspondingly which module of the language system is impaired.

Even though language and cognition are independent, and can be selectively affected, they necessarily interact in the normal use of verbal communication. When we speak, we must speak about something, hence we need to access episodic and/or encyclopedic memory if we are to encode anything in the sentences we produce. And whereas aphasic patients lose access to some or all aspects of the language system and amnesiac patients lose access to their episodic and encyclopedic memory (or are unable to acquire any new such memories), patients with dementia of the Alzheimer type, whose cerebral deterioration may be more diffuse and/or more topologically extensive, may exhibit deficits in both language and cognition.

With respect to the second question, the semantic store of psychologists contains all of our knowledge, including our knowledge of the lexical meaning of words. To the extent that individuals are asked to recall a previously presented item, experiments are tapping episodic memory: whether a happy face was flashed on the screen, or the word «happy», the experimental subjects must remember an event. In the case of words, they must remember the phonological form + meaning; that is, it is not sufficient to extract the meaning and discard the form as one does in the normal use of language. The point I wish to make here is that, whereas it is perfectly legitimate to decompose a complex cognitive task into its component parts in order to make that task amenable to experimentation, albeit piecemeal, we must be careful that the tasks used in

experimental psycholinguistics, including on-line tasks, do tap an actual component or stage of the process of the normal microgenesis of an utterance.

A point of detail: If a patient is unable to name a certain item only some of the time, we may safely conclude that the item itself is not destroyed, that it is a problem of access (or inhibition). On the other hand, «if the patient is consistently unable to name a certain item», there is no evidence that the item itself is or is not impaired. The marked variability of performance of patients with dementia of the Alzheimer type tends to support the hypothesis of difficulty of access to explicit memory, which brings us to Loraine Obler's third and last point.

The data that Dr. Obler referred to in her presentation provide additional evidence that patients with dementia of the Alzheimer type retain the functions subserved by (implicit) procedural memory while they lose access to the functions subserved by (explicit) declarative memory; procedural and declarative memory representing two neurofunctionally, neurophysiologically and neuroanatomically distinct systems (Cohen & Eichenbaum1993).

It has been observed by Chapman (1996), among others, and by Loraine herself this morning, that patients with dementia of the Alzheimer type lose access to their vocabulary from the very first stages of the disease, with good retention of syntax, phonology and morphological rules until the very last stages. It turns out that vocabulary is the most explicit component of the language system (at least the phonological form and referential meaning of words are explicitly known). Vocabulary stands apart from the rest of language structure in several ways: Chimpanzees and gorillas have been reported to have been able to learn large numbers of words; children deprived of language input between the ages of one and seven or eight (and a fortiori later: Victor of Aveyron, Genie) also manage to master a large vocabulary but like non-human primates, very little morphosyntax; the idiot-savant reported by Smith & Tsimpli (1995) has been able to accumulate a considerable vocabulary in several languages (as well as other factual knowledge about these languages) but no grammar to speak of. On the other hand, H.M., probably the most studied amnesiac patient in the world, has never been able to acquire new words. (He did not know the word 'cupidity' in 1956 and still does not know it today in spite of numerous attempts to teach it to him (Cohen, 1991)). Yet, H.M. has been able to acquire new motor as well as cognitive skills at the same rate as non-amnesiac individuals.

Convergent evidence from various sources thus seems to point to a differential loss of explicit relative to implicit memory in Alzheimer's disease, in double dissociation with aphasia and Parkinson's disease, in which declarative memory is spared in the context of deficits in functions subserved by (implicit) procedural memory. Implicit and explicit memory have been doubly dissociated in patients with Alzheimer's Disease (Gabrieli, Reminger, Grosse & Wilson, 1992), alcoholic Korsakoff's syndrome (Cavanan, Hömberg & Stelmach, 1992; Parker, 1992), anterograde amnesia (Corkin, 1992; Keane, Clarke & Corkin, 1992), Parkinson's Disease (Saint-Cyr, Taylor & Lang, 1987), aphasia and apraxia, as well as by anesthetic techniques (Cork, Kihlstrom & Hameroff, 1992). Patients with Alzheimer's Disease, Korsakoff's syndrome, or amnesia have impaired explicit memory but intact implicit memory; patients with Parkinson's

Disease demonstrate a selective impairment of procedural memory; whereas patients with aphasia have impaired implicit memory for language (or of the automatic use thereof), without loss of explicit knowledge. Anesthesia with isoflurane/oxygen spares implicit memory (Kihlstrom, Schacter, Cork, Hurt & Behr, 1990), but not with sufentanil/nitrous oxyde (Cork, Kihlstrom & Schacter, 1992). Neither, fortunately, spares explicit memory.

Loraine Obler's paper brings further grist to the mill. The fact that patients with dementia of the Alzheimer type are reported to have a tendency to use their first language exclusively (or at least in contexts where it is not appropriate) would support the hypothesis according to which the second language, when learned in adulthood, relies to a greater extent on explicit metalinguistic knowledge than the first acquired language. Ribot (1891), after all, was mainly concerned with retrograde amnesia when he declared that later acquired memories were more vulnerable than early acquired ones. It is not surprising that patients with dementia of the Alzheimer type would conform to Ribot's prediction. The reverse situation is exemplified by aphasic patients who have been reported to be able to speak only, or much better, their second, premorbidly much less proficient language.

Bilingual patients with dementia of the Alzheimer type do not so much demonstrate an inability to use each language in their respective appropriate contexts, as the selective loss of access to the second, later learned language, a condition which forces them to use their native language in all circumstances. As I pointed out earlier this morning, the fact that some bilingual aphasic patients seem to recover their premorbidly least proficient language may be due to their equal loss of implicit linguistic competence in both languages, and their reliance on explicit metalinguistic knowledge which may happen to be much more extensive in their second language. The reverse pattern seems to be exhibited by patients with dementia of the Alzheimer type, a double dissociation that further underscores the theoretical as well as clinical importance of distinguishing procedural from declarative aspects of the language system.

The so-called «regression» to the first language, not seen in aphasic patients (who have an impaired implicit linguistic competence), is observed in patients with dementia of the Alzheimer type (who have an impaired episodic and encyclopedic (declarative) memory in general and in those declarative aspects of language, namely vocabulary, in particular). Note that I am not using the technical term 'lexicon' because a lexical entry contains features other than the explicit phonological form and referential meaning of the word, such as implicit morphological and syntactic properties. Of course, *access* to the lexicon is also implicit, and some aphasic patients exhibit word finding difficulty though no problem in recognition of either referential meaning or phonological form.

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What Bilingual Aphasia Tells Us About Language Processing in the Unilingual Brain

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The study of bilingual aphasia has made us focus on a number of issues that have proven useful for the understanding of aphasia in unilinguals and of the way the brain processes language in general: (1) An attempt to account for the various recovery patterns has led to the notion of inhibition/disinhibition in the use of languages, and of activation threshold of the various language subsystems in unilinguals as well; (2) sociolinguistic registers in unilinguals have come to be viewed as neurofunctionally fractionable in the same way as two languages in the brain of bilinguals; (3) the dissociation between linguistic competence and metalinguistic knowledge in second language learners has led to a better grasp of the roles of procedural and declarative memory in language acquisition and use; and (4) the study of the use of pragmatic features in order to compensate for the lack of linguistic competence in second language speakers has shed light on the role of pragmatics in normal language processing as well as in 2-year-olds' incipient first language acquisition and in unilingual aphasic patients.

Each of the above considerations has implications not only for our understanding of the way languages are represented and processed in the brain, but also for a better diagnosis and rehabilitation of neurogenic communication disorders. We shall briefly consider each of these four issues in turn.

Patterns of Recovery and Explanations: Activation Threshold

Because bilingual aphasic patients do not always recover both languages to the same extent or at the same time, and in fact one of the languages may never be recovered, some authors had speculated that perhaps each language was located in a different part of the cortex. Pitres (1895) proposed instead that each language independently could be temporarily or permanently inhibited. This suggestion prefigures two present-day notions: that of modularity of language systems and that of differential inhibition which in turn led to the activation threshold hypothesis (Paradis, 1993).

Certain recovery patterns, reported long after Pitres's monograph, confirmed his insight. Antagonistic recovery, and in particular alternating antagonism could definitely not be accounted for by differential localization. For, if the reason why a patient could not speak Arabic on Monday was that its neural substrate had been destroyed, in contrast with French, located in an area that had been spared by the lesion, and hence that she could speak, how could we explain that, on Tuesday, she was able to speak Arabic again, but not French? Or in the case of successive recovery, that a language spontaneously recovered several months later? Thus, the temporary or permanent inaccessibility of languages must be accounted for by something other than location at different cortical sites.

Pitres proposed that the neural substratum of languages that are not accessible is not physically destroyed but functionally impaired. This inhibition, however, is not an all-or-nothing phenomenon: it admits of degree of severity, as evidenced by languages that are more impaired than others in cases of differential recovery. It was quickly assumed that, in the normal use of language, in order to avoid interference, one language was being inhibited while the other was activated (on the model of any function and its antagonist).

However, experimental evidence showed that the language not currently in use was nevertheless never totally deactivated (Green, 1986; Grosjean & Soares, 1986). It had also been observed that in non-brain-damaged individuals, language items were sensitive to frequency and recency of use, in that they were more easily available when they had been frequently or recently used. Elements that have been activated show a priming effect: they are easier to activate again. From these various observations emerged the Activation Threshold Hypothesis.

The Activation Threshold Hypothesis proposes that an item is activated when a sufficient amount of positive impulses have reached it. The amount necessary for the item to be activated is its activation threshold. Every time the item is activated, its threshold is lowered, and fewer impulses are then required to reactivate it. After each activation, the threshold is lowered but it gradually rises again and if it is not stimulated, becomes more and more difficult to activate. Attrition is the result of long term non-stimulation. Comprehension of a given item does not require a threshold as low as for production of that item. In other words, comprehension requires fewer impulses than production, and is thus easier. This is probably due in part to the fact that the item is activated by the impulses generated by the stimulus as it impinges on the senses. No such external support exists for self-activation of an item, hence the total sum of the impulses required to reach the activation threshold have to be internally generated. Entire systems or subsystems may be inhibited in this way (their threshold raised beyond possible activation). Thus, after a long period of disuse, one of the languages might still be understood but no longer spoken spontaneously. This is of course true of any item within each language.

Pathology (or normal aging) may disrupt the normal activation levels, causing word finding difficulty, for example. Aphasia would correspond to the blanket raising of the threshold of a system, or subsystem, or module, thus selectively or differentially affecting the entire language system, or one of the languages, or phonology, syntax, or lexical access in only one of the languages. The hypothesis can be extended without modification to unilingual systems.

Neurofunctional Modularity: Sociolinguistic Registers

After considering a number of possible ways in which the two languages of a bilingual speaker might be represented in the brain, and having rejected the extended system, the dual system, and the tripartite system (Paradis, 1987a) as not being compatible with all of the reported data, the Subsystems Hypothesis was adopted as the most adequate working hypothesis. It proposes that each of the languages forms a subsystem within the larger system of language. The various dissociations between languages in bilingual aphasia have shown that each language is capable of selective impairment, and hence must at some level constitute a coherent neurofunctional system. But the ability to mix languages without apparent loss of fluency and cross-linguistic priming point to both languages being part of a larger system, the language faculty, which can selectively be inhibited as a whole, with other cognitive functions remaining relatively intact.

A comparison between unilinguals and bilinguals revealed that there are no functional differences between them: Borrowing, mixing, switching, and translating have their unilingual counterpart in using words from different registers, switching registers in response to changes in the social contexts, and paraphrasing (that is, relating the same message in different words, sometimes with a different pronunciation, syntax and morphology, as well as different lexical items). This led to the assumption that there were probably no neurofunctional differences either, and that therefore, the brain of a unilingual should be organized in the same way as that of a bilingual, with its registers organized in the same way as the languages of multilinguals. The study of Japanese dyslexia, with its double dissociations between the various writing systems (kana and kanji, Roman and kanji numerals), as well as dissociations between musical notation, morse code, or shorthand and cursive writing, and between languages in bilingual aphasic patients led to the hypothesis of neurofunctional modularity (Paradis, 1987b). The Subsystems Hypothesis was then extended to cover the different registers of unilingual speakers as well. One could thus expect the same kind of dissociation between registers in unilingual aphasia as have been observed in bilingual aphasia. Indeed some cases of such dissociations have been described, between formal and familiar registers (Riese, 1949) and between Cockney and Oxford dialects but such reports remain few because the phenomenon has not been systematically investigated so far. Once one starts looking for them, more cases are likely to be found.

The Role of the Right Hemisphere in Language Processing

A major question about the bilingual brain has been the extent to which it might differ from the unilingual brain. On the basis of results from a few dichotic listening and visual half-field tachistoscopic studies, it was first speculated that language organization in the brain of the average bilingual may be more bilateral than in that of a unilingual and that patterns of cerebral

dominance may be different for each language in the brain of a bilingual (Albert & Obler, 1978). Even at that time it was apparent that the few studies on which the differential lateralization hypothesis was based presented several contradictions. As additional studies failed to support predictions, the hypothesis was gradually narrowed to apply to more and more restricted subgroups of bilinguals: Late acquirers (the age hypothesis), late acquirers at the beginning stages of acquisition (the stage hypothesis), late acquirers at the beginning stages of acquisition in an informal environment (the stage + manner of acquisition hypothesis). While many studies continued to find no difference, those studies that did report a difference were making contradictory predictions. For example, in direct contradiction with the stage and manner hypothesis, students in a *formal* learning environment were reported to become less lateralized as they became more proficient (Bergh, 1986). Finally, a meta-analysis of all the available experimental data could not find evidence of lesser asymmetry of language representation in the brains of bilinguals of any type (Vaid & Hall, 1991). Clinical studies have consistently reported the same incidence of crossed aphasia in bilingual as in unilingual subjects (Chary, 1986; Karanth and Rangamani, 1988; Rangamani, 1989), suggesting that the contradictory results of experimental studies might be due to the lack of validity of the laterality paradigms used in these experiments, given a 90% chance of misclassification of subjects into a right-brain language group, as was argued 20 years ago by Satz (1977). Colbourn (1978) also pointed out that there was no foundation for the assumption that the degree of a performance asymmetry reflects the degree of lateralization for the task or stimulus material used.

An inquiry into what the alleged increased participation of the right hemisphere might consist of (Paradis, 1987a) has led to the realization, on the basis of language-related deficits reported in right-brain damaged patients, that non-balanced bilinguals might well rely to a greater extent on pragmatic aspects of language in order to compensate for the gaps in linguistic competence in their weaker language. It became clear that in order to derive the meaning of any utterance in context that is, in the normal use of language both linguistic competence and pragmatic competence are needed. Both are necessary, but neither is sufficient, and each is subserved by a different hemisphere (Paradis, 1994a). A left hemisphere lesion will result in dysphasia (the disruption of phonology, morphology, syntax and/or the lexicon); a right hemisphere lesion will result in dyshyponoia[1] (an impairment in making appropriate inferences from the context or from general knowledge).

The use of pragmatic features to compensate for lack of linguistic competence is also a fact of incipient first language acquisition (Bloom, 1974). It then becomes apparent that there is no

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1. Dyshyponoia: From the Greek ὑπονοώ what is «undestood» in an utterance, albeit unsaid, in the sense of the French *«sous-entendu»*, Spanish *«sobrentendido»*, Catalán *«sobreentès»)*. Impairment of the use of linguistic pragmatics (e.g., the inability to draw correct inferences from the context or from general knowledge, leading to problems in the interpretation of indirect speech acts, metaphors, and in general of the unsaid component of an utterance).

clinical evidence of right hemisphere involvement in the processing of linguistic competence in unilingual two- to five-year-old children. The original rationale for suspecting the involvement of the right hemisphere in the beginning stages of second language acquisition was that it recapitulated first language acquisition. But there is no evidence that children process grammar (i.e., phonology, morphology, syntax, and the lexicon) in the right hemisphere even at the earliest stages of language development. There is therefore no foundation to the assumption that the acquisition of linguistic competence in a second language, like that in the first, would involve the right hemisphere in the beginning stages. Second language acquisition may indeed recapitulate the sequence of processes engaged in first language acquisition, including right hemisphere participation but by implicating pragmatic, not linguistic competence.

(I assume researchers that claimed right hemisphere participation for language referred to grammar since they used methodologies that purport to measure language *as it is represented in the left hemisphere of unilinguals*, and could not be influenced by right hemisphere-based pragmatic features without admitting that their procedures were invalid (i.e., not measuring what it is purported to measure). In fact it is difficult to see how results could be contaminated by pragmatics when the stimuli consisted in digits, syllables or, at best, isolated words).

The Use of Metalinguistic Knowledge and Implicit Linguistic Competence

Another means by which second language speakers are able to compensate for their lack of linguistic competence is metalinguistic knowledge. While competence in a native language is acquired incidentally, i.e., by focusing attention on some aspect of utterances other than that which is internalized (e.g., on meaning while acquiring a grammar; on acoustic properties of sounds while acquiring motor programmes for the production of those sounds); is stored implicitly (i.e., outside the scope of awareness) and remains for ever opaque to introspection, and is used automatically (i.e., without conscious control); metalinguistic knowledge, on the other hand, typically encountered in school, is learned consciously, that is, by paying attention to what is memorized, can be recalled and recounted, and is produced in a controlled manner. The observation that some language students who obtain good marks in school do poorly in conversational settings, while some students who obtain poor maks communicate quite fluently (albeit not necessarily very accurately) drew attention to the implicit linguistic competence/explicit metalinguistic knowledge distinction.

Clinically a double dissociation is observed between amnesiac and aphasic patients. Anterograde amnesiac patients are unable to acquire new knowledge, in fact to remember anything of which they have been conscious since the onset of their condition. They cannot remember where they parked their car or what their new address is if they have moved. They cannot learn new words or remember the names of new acquaintances (or remember having seen them before) or new place names (like the name of their new hospital or town). Yet, they

are able to acquire new motor or cognitive skills and show the same improvement with practice as normals, without ever being aware of having encountered the task before. In other words, their declarative memory (knowing that) is impaired but their procedural memory (knowing how) is intact. Aphasic patients, on the other hand, have deficits in the procedural memory system that subserves their language competence (a cognitive skill) but have no problem with declarative memory. Implicit competence is represented in those cortical areas that were active in their acquisition. Thus implicit linguistic competence is represented in the perisylvian area long identified as the «language area» including Broca's area in the frontal lobe, and Wernicke's area in the temporal and parietal lobes of the left hemisphere. Declarative knowledge, of which explicit metalinguistic knowledge is a part, is bilaterally represented in large areas of associative cortex. The metalinguistic rules of pedagogical grammar, like most overlearned material, may in fact be represented preponderantly in the right hemisphere.

The amnesiac patient's difficulty with learning new words has highlighted a distinction between morphosyntax and vocabulary. While morphosyntax (as well as phonohology) is implicit, vocabulary is to a large extent explicit: speakers consciously know the sound and the meaning of words and can produce either on demand —something they cannot do about the algorithms that underlie morphosyntax or phonology (professional linguists themselves continue to disagree on the form of linguistic representations, a testimony to the opacity of implicit linguistic competence). Lexical access and the automatic insertion of lexical items in the course of the microgenesis of an utterance produced under normal circumstances is equally unavailable to awareness. In addition, there is a clear dissociation between phonology and morphosyntax on the one hand and vocabulary on the other in individuals with genetic dysphasia (Paradis & Gopnik, 1997), in children who are not exposed to language until seven (Lebrun, 1978) or thirteen (Curtis, 1977) years of age, for whom the acquisition of implicit grammar is arduous, whereas vocabulary expansion is relatively easy.

The declarative and procedural memory systems are not only neurofunctionally distinct, but involve different subcortical neural structures. The acquisition of declarative memory relies crucially on the integrity of the hippocampal system whereas procedural memory engages other subcortical structures, such as the basal ganglia (Butters, Salmon & Heindel, 1994; Dubois, Malapani, Verin, Rogelet, Deweer & Pillon, 1994), the striatum, as well as the cerebellum (Leiner, Leiner & Dow, 1991; Ito, 1993). Both memory systems depend upon cortical and subcortical structures, but different ones.

These observations led to a reconsideration of the selective or differential paradoxical recovery of some bilingual aphasic patients who had recovered their least known language over their previously fluent native language. It may well be the case that patients who have no longer access to the procedural memory system underlying linguistic competence for both their languages have nevertheless retained access to their declarative metalinguistic knowledge which may be more extensive in their formally learned second language. This may also explain the observed better prognosis that is generally correlated with a higher level of education in

unilingual speakers. One may speculate that metalinguistic knowledge should still be available (or taught) to aphasic patients and thus compensate for their lack of access to their implicit linguistic competence, in the way that individuals with genetic dysphasia and some second language learners do.

Conclusions

What applies to the bilingual brain also applies to the unilingual brain: there are no qualitative differences. Individuals find themselves on a continuum from several registers in a unidialectal speaker to bidialectal speakers, to speakers of closely related languages, to speakers of unrelated languages. All use the same cerebral mechanisms, albeit to differing extents.

When the procedural memory system for language is genetically impaired or when the system has not been engaged during the time of its normal development (i.e., between the ages of 2 and 5), speakers compensate (for their lack of competence in their first or second language) from two sources: right-hemisphere-based pragmatic competence and metalinguistic knowledge. Unilingual individuals with acquired aphasia should have the same options.

The evidence points to a neurofunctional modular system for language representation, with specific neuroanatomical substrates, irrespective of the number of languages stored in the brain. Differences between cerebral processes involved in language representation and use in unilinguals and different types of bilinguals appear to be only quantitative, as speakers of a second, weaker language may rely to a greater extent on explicit metalinguistic knowledge and pragmatic features to compensate for lacunae in their implicit linguistic competence. *What* is represented may differ, *how* it is processed does not. However, if the results reported by Weber-Fox and Neville (1996) are confirmed, namely, that bilingual individuals after the age of six or seven process functional items as lexical items, then it may be that later acquirers of a second language, like individuals with genetic dysphasia (Paradis & Gopnik, 1997), do in part process language in a qualitatively different manner. A distinction will then be necessary between bilinguals that is, *early* bilinguals and fluent speakers of a second language.

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Esteemed colleagues, I'm terribly sorry to miss the conference as there is much I stood to learn from all the speakers, and from the discussions at the conferences. I'm indebted to Professor Argenter and Ms. Portet for all the work they have done in convening this conference and for their gracious hospitality for me during the days I was able to spend in Barcelona before my son's unfortunate accident. I have written out my comments on Professor Paradis's paper so I can contribute to the discussion at a distance; as you can imagine, I look forward with excitement to the final publication so I can learn what I missed.

I consider myself quite fortunate to have had this opportunity to read carefully Professor Paradis's conceptual summary of his research and theorizing to date in the context of the larger discussions about bilingual aphasia and neurolinguistic understandings of the brain.

Professor Paradis's notion of the Activation Threshold Hypothesis is a useful one in the context of Parallel Distributed Processing models of language organization and use. As he points out, languages that have not been used for a period are inhibited in their use. One must recall that they can be reprimed as a result of re-immersion in the language. Norman Geschwind used to recall how Eric Lenneberg would tell about his re-immersion in his languages. Lenneberg was born in Germany, but his family moved to Latin America to escape the Nazis. Then he came to the United States where his professional life was conducted in English. When he would return to Latin America to visit his family, there would be some days during which the recovery of *his* native German and his adoptive second language would be slow, but then he would «recover» them within, as I recall, about a week. This is precisely the sort of repriming that Paradis's Activation Threshold Hypothesis would predict.

It may be useful to refine the notion of Activation Threshold further to account for the second language acquisition phenomenon reported by Bahrick. He was not looking at people who had achieved fluent bilingualism as Lenneberg had, but rather second-language learners. In studying a large sample (over 800 as I recall) who had not been using their second language —Spanish— for between eight years and several decades, he demonstrated that there is a fall-off in second language knowledge for about five years after learning has ended and then a plateau of about

twenty-five years during which no further previously-achieved knowledge is lost. Further decline was seen after twenty-five years, but he pointed out that this may not reflect second language attrition *per se*, but rather the effects of aging (he had not tested language performance in the first language). Paradis's Activation Threshold Hypothesis as he discusses it in the paper we have heard today would suggest a simple progressive linear decrease rather than Bahrick's 5-year linear decline followed by an extended plateau, although of course Paradis's hypothesis is not altogether inconsistent with Bahrick's data.

Paradis's Subsystems Hypothesis is particularly attractive to me. Long ago, in a book Michel Paradis edited, Martin Albert and I talked about the notion of modularity in bilinguals, noting that the Stroop effect was diminished but never nonexistent in bilinguals, and linked to relative proficiency in the two languages. The Stroop effect, you may recall, is the phenomenon whereby even when you are asked only to label the ink colors of words, particularly if the words are names of other colors, it is impossible not to be distracted, and thus slowed down, by the printed words. The phenomenon in bilinguals is particularly interesting because while bilinguals are slowed down if the words are printed in a language other than the one they are to be speaking, they are able to inhibit speaking the actual words, but they speak their translation equivalent in the language they have been instructed to use. Thus at the same time, from such a task, we have evidence that, for production at least, relatively separable systems can be maintained, while for comprehension the borders between languages may be murkier. In Paradis's terms, it seems to me that the Activation Threshold remains somewhat lowered for any language that may be input. Indeed, quite early —I believe in our 1978 book— it was clear to us that neither the coordinate or compound models made entire sense given the psychological literature, with some tasks suggesting that bilinguals were coordinate while other tasks suggested they were compound. What made sense, we agreed, was compounded systems for those aspects of the two languages that are quite similar and need not be kept dissociated, with more coordinate subsystems for those systems that are more different.

I was interested in Paradis's observation that the reason we have not seen dissociations in the aphasia literature between formal and familiar registers is that researchers have not looked for them. It should be pointed out that in the discussions about whether there is more crossed aphasia in bilingual subjects —that is, aphasia resulting from right hemisphere lesions in a right-hander, suggesting right hemisphere dominance for language— it is generally understood that the reason so many such cases of crossed aphasia are reported in the literature is because they are surprising and thus publishable. If one simply did a count of such cases in the literature, as Linda Galloway did, or as we did in our 1978 book, one would see that they form a disproportionate number of the cases of bilingual aphasia that have been reported. Once one does studies of all patients entering any institution, as April and Tse did, one realizes that the percentage of crossed aphasias in bilinguals or polyglots is no greater than that in monolinguals. However, one might equally suppose that a phenomenon of differential register employment would be equally noticeable, but I realized in thinking about Professor Paradis's point that there

is a certain asymmetry in what would be noticeable. If an aphasic patient is simply speaking more colloquially than previously, this is not likely to stand out, as one would assume that with limited language availability more colloquial language would be easier to use. It's only the contrary instances, when a more formal register is spared and used in informal situations that would be striking. I remember where I stood in the Library of Hadassah Hospital in Jerusalem some twenty years ago when I first came across the report of such a case. At the time I didn't realize how unusual such a case would be and I was never able to relocate it despite searches of the many bookcases in that corner of the Library, after I realized how unusual such a case report was! Moreover, such cases are likely to be rare as many academics in the world can get through life without a terribly formal register, at least in the societies which have been doing most neurolinguistic publishing. Professor Paradis would know more about the literature that has been published on Japanese-speaking aphasics, and here is certainly a literature where loss of the formal structures that pervade the language system should be quite striking. It is, I should note, conceivable, however, that there may be markedly fuzzier boundaries between the formal and informal registers of languages than there are between the two languages of the bilingual. This would make it less likely for a register dissociation to stand out as compared to the dissociation one might see for the frankly bilingual subject.

As to Professor Paradis's consideration of the role of the right hemisphere in language processing, I must admit after I pulled together the sizable number of individuals who have published in the areas of language laterality and bilingualism at a BABBLE conference in the early 1980's and then published a critique of the methods used in that literature, I have lost substantial interest in the question of hemispheric participation in bilingual language organization and processing. The aphasia literature is quite clear in this regard; as I mentioned above there is no increase in the number of crossed aphasics which would suggest substantial right hemisphere impairment. Rather the «interesting» findings come from laterality studies. My own contributions in this area, as well as my critique of the literature of those of others (Zatorre) make clear that numerous factors can enter into language processing as it is reflected in tachistoscopic and dichotic studies. It is true that my name is associated with the belief that there is increased right hemisphere participation in the early stages of second language acquisition, based on the work we did in Silverberg et al. where we demonstrated that seventh grade Israeli Hebrew speakers showed substantially more bilateral organization for their English (but not for their Hebrew, which was already quite proficient) than did ninth and, even, less eleventh graders. In the paper we've heard today, Michel Paradis would attribute such findings to pragmatics, and I would invite him to speak somewhat more about the specifics of pragmatics that he has in mind, since this term can be used quite generally —to include, for example, eye contact during language use, appreciation of humor, etc. — as well as more narrowly — for example to discuss inferencing or the fronting of items in sentences. What specific forms of pragmatics are you assuming enter into the right hemisphere processing that is seen in some studies of lateral organization of bilinguals, either for the second language or for both languages as compared to

monolinguals? I ask this question because when Martin Albert and I spoke about the right hemisphere processing that appeared more evident in our data in the early stages of second language acquisition, we suggested, as I recall, that it might reflect the strategies used for performing the tasks in a less well-known language. I've not considered such strategies to be an aspect of pragmatics, but perhaps there is a link there.

The final point I would like to discuss briefly is Michel's discussion of metalinguistic abilities. His point is very elegant that professional linguists disagree on the forms of linguistic representation, so we can rest confident that they are opaque to speakers, While it is true that in school we learn a number of rules of language, I would maintain that these are not what most researchers mean by metalinguistic knowledge nor are these rules likely to be represented in the right hemisphere given what little we know of what language it is responsible for. My reading of the literature on right-hemisphere language suggests that highly concrete and visualizable as well as emotionally-laden lexical items are likely to be represented there —perhaps dually represented there and in the left hemisphere. I'm unclear why Michel says that the «rules of pedagogical grammar like most overlearned material» may be represented in the right hemisphere, since my reading about overlearned materials was that the left hemisphere took responsibility for them. I'm thinking particularly of the studies of lateral organization in musicians, whereby less proficient musicians showed right hemisphere dominance for musical processing, whereas professional musicians showed left hemisphere dominance. Moreover, language itself can be considered to be quite overlearned, and we do know that the left hemisphere is dominant for language in virtually all humans. The use of the term «metalinguistic» in the literature I read involves unconscious abilities, such as the ability to determine how many phonemes there are in a given word, and this metalinguistic knowledge can be available even before school starts (indeed it's one of the predictors of how good a reader the child is likely to be), I do know that others use the term «metalinguistic» in many different ways, but I don't believe I've yet come across this particular usage that Michel employs here, whereby it is, apparently exclusively, «learned consciously».

I particularly regret missing the conference because I'd love to hear of Paradis's recent work on children. I do recall in a recent study with Gopnik, they reported on morphosyntactic deficits in these children, but I'm particularly interested to hear of how these morphosyntactic deficits link to phonological deficits, with vocabulary expansion relatively spared.

In response to Loraine Obler's request to specify the pragmatic aspects on which I speculate bilingual speakers may rely more when using their weaker language, I mean any inference from general knowledge and/or situational context, including paralinguistic phenomena such as affective prosody, mimicry and gestures, in other words, any clue that may help overcome the lack of grammatical means to derive or convey meaning.

Note that I emphatically do not attribute reported experimental results of greater right hemisphere involvement to pragmatics. I have relentlessly argued (Paradis, 1990, 1992, 1995) that it could not be the case. It is difficult to envisage how results from the dichotic presentation of meaningless syllables, digits, or isolated words could possibly be influenced by any aspect of pragmatics. The same goes for the tachistoscopic presentation of isolated words in visual hemifields or counting backwards while tapping with the right or left hand. It is difficult enough to see how these results could be generalized to the language system as a whole (i.e., the grammar). What I interpret the contradictions to mean is not that some of the results are contaminated by pragmatics, but that the paradigms involved have not been shown to be reliable or valid in determining degree of laterality of language and do not correlate with clinical findings, as had already been argued 20 years ago (Sacks, 1977; Colbourn, 1978).

What I am saying is that, if there is a sense in which there may be greater right hemisphere participation in verbal communication in bilinguals, it could be because of a greater reliance on pragmatic clues to compensate for gaps in implicit linguistic competence in their weaker language. These aspects are not «seen in some studies of lateral organization of bilinguals», at least not in the experimental studies of the dichotic, tachistoscopic or tapping types. They could only be revealed by on-line brain imagery techniques (PET, fMRI, EEG) that simultaneously look at both hemispheres during real language processing (i.e., the comprehension and production of utterances in context) and control for grammatical and pragmatic contents.

A second available compensatory strategy is the use of metalinguistic knowledge. These rules are not assumed «to be represented in the right hemisphere», but, as part of declarative knowledge, to possibly be diffusely represented over large areas of both hemispheres. A number

of neuropsychologists would maintain that stereotypic, overlearned formulae, memorized verbal material (prayers, poems, lyrics, sayings), are represented in the right hemisphere, and use this assumption as an explanation for the availability of such items to severe aphasics when all other forms of language are lost. Personally, I have always thought that areas of the left hemisphere adjacent to the classical language zones might be just as likely candidates, but I know of little solid evidence on the subject. All I am saying is that, if overlearned material is stored in the right hemisphere (and declarative knowledge of metalinguistic facts is such knowledge), then to the extent that metalinguistic rules are used to compensate for gaps in implicit linguistic competence, the right hemisphere might be more involved. If metalinguistic knowledge, as part of declarative knowledge, is bilaterally represented, then again, there would be greater right hemisphere involvement than in the use of implicit linguistic competence alone, though to a lesser extent. But this assumes lots of ifs. My point is simply that whatever greater participation there is, it is not implicit linguistic competence (phonology, morphology, syntax and the lexicon) for either L1, L2, or both.

The ability to determine how many phonemes there are in a given word is not an unconscious ability. Such judgments are verbalized by the subjects (and hence subserved by declarative memory) and are based on the subjects' ability to observe actually produced words, again an explicit process. Whatever metalinguistic knowledge there is, whether learned in school or arrived at by personal observation before school, is, by definition, conscious and declarative. If it were not, it would be implicit competence, not explicit knowledge. While knowledge may be obtained by means other than deliberate, it is definitely part of speakers' awareness, otherwise they would never be able to verbalize their metalinguistic knowledge, and hence tell you how many phonemes there are in a given word. Phonemes may be used implicitly, but if you know and can tell what they are, they are necessarily part of your awareness, hence conscious.

For information about the phonological and morphological abilities of individuals with genetic dysphasia, as alluded to by Professor Obler in her comments, please consult the special issue of the *Journal of Neurolinguistics* (1997), volume 10, number 2/3.

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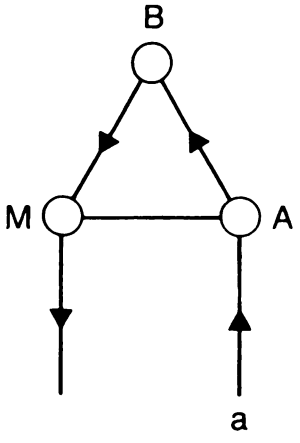

Figure 1: Lichtheim's model of word representation. Separate and autonomous representations of the articulatory form (in motor center M), sound pattern (acoustic center A) and meaning (concept center B - German «Begriff» means «concept») are postulated. Adopted from Ref. 2.

The problem of language and the brain has caught the attention of neurologists, psychologists and linguists since the second half of the 19th century, when Broca[1] published his seminal description of language loss due to brain lesion (aphasia). It was in these early years of the language-and-brain sciences when a simple model of cortical language mechanisms was proposed. This model posits that two small centers in the left hemisphere of typical right-handed individuals are the «seat» of word representations (Figure 1)[2,3]. More precisely, a motor language center housed in the left inferior frontal lobe (areas 44 and 45, see Figure 2) was believed to store articulatory plans of words, and a separate acoustic language center in the left superior temporal lobe (area 22) was believed to house the sound patterns of words. Although the exact definition of these «language centers» somewhat varies between different authors[4], they are usually localized close to the sylvian fissure and are, therefore, part of the «perisylvian» areas.

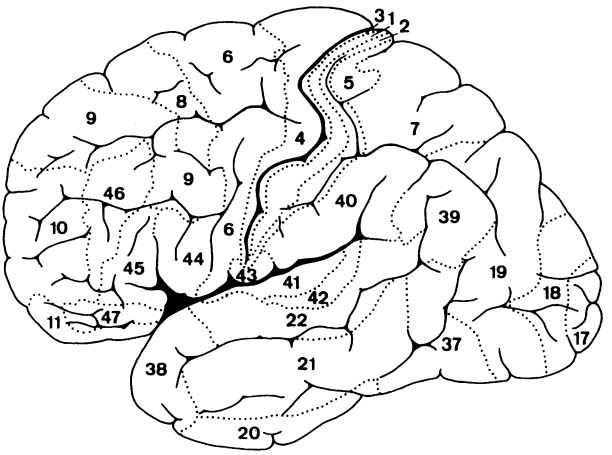

Figure 2: Lateral view of the left cortical hemisphere. Brodmann's areas are indicated. Adopted from Ref. 52.

This narrow localizationist view was subject to some criticism already before the turn of the century, which was formulated, for example, by a famous psychoanalyst who did some brain science in his early career. Based on theoretical considerations, this researcher claimed that processing of individual words should involve not only the two small perisylvian centers in the left hemisphere, but additional widespread cortical areas that are, for example, essential for visual perception. According to this author, there are not two separate brain-internal representations of articulatory plans and sound patterns of words, but, instead, a widely distributed neuron network would represent the articulatory and acoustic word form together with its meaning. Figure 3 presents a sketch of such a network.

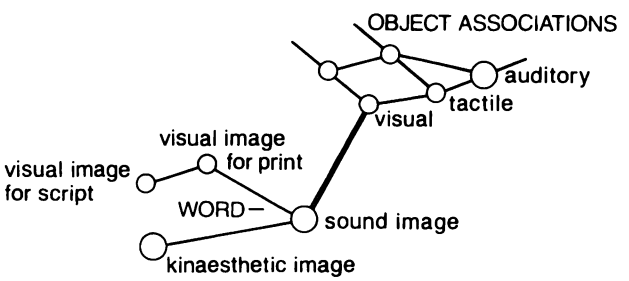

Figure 3: Freud's model of word representation. A widely distributed network is assumed to represent the various aspects of a word (articulatory and acoustic pattern, semantic properties). Lesion anywhere in the network may impair its function. Adopted from Ref. 15.

Are there arguments that would support one or the other view- either the narrow localizationist view of Wernicke and Lichtheim, or the holistic view put forward by Freud?

According to what is known from aphasia research, lesions of Broca's area and adjacent areas in the inferior frontal lobe of the language-dominant hemisphere lead to motor aphasia characterized by severe deficits in producing speech, and lesions in Wernicke's area in the superior temporal gyrus causes sensory aphasia, for which a deficit in understanding language is most characteristic. These facts appear to speak in favor of the localizationist model.

However, after lesion in Wernicke's area additional deficits in speech production can be observed, and after lesion in Broca's area the patient usually exhibits additional problems in comprehending sentences. Although there are a few cases in the literature for whom it has been claimed that there is a language production deficit without any deficit in language comprehension[5], a test of language comprehension (and short-term verbal memory), the so-called Token Test[6], is usually clinically used for aphasia diagnosis. Thus, it appears that the large majority of aphasics, even those who have one intact language area, exhibit deficits in both language production and comprehension, although one of these deficits may be more pronounced than the other. This fact can only be explained if both language areas are assumed to contribute to both language production and comprehension, a fact which obviously speaks against the narrow localizationist approach and supports the holistic view[7]. However, one may nevertheless object against the holistic approach that probably not all cortical areas are equally involved in word processing, and that the areas involved may not be the same for different parts of speech. In summary, the truth appears to lie in-between the classical localizationistic and holistic views. A brain-theoretical framework is necessary in order to allow for more specific postulates.

One of the most important neuropsychologists of this century, Donald Hebb[8], proposed a brain-theoretical framework that may be of particular relevance for language representation and processing. Hebb assumes that the cortex is an associative memory machine and the strength of connections between cortical neurons depends on how frequently these neurons have been co-activated in the past. Meanwhile, there is strong evidence for this view from both neuroanatomy[9,10] and neurophysiology, although the original Hebbian ideas about learning principles had to be modified based on physiological data[11] and computational considerations[12]. If several neurons are frequently active at the same time, they will acquire strong connections to each other and, therefore, this «cell assembly» will act as a functional unit: If only some of its neurons are being activated by external input, activity will automatically spread throughout the assembly so that all of its members will be active. This explosion-like process has been called ignition of the assembly[9]. Furthermore, if an assembly has ignited, neuronal activity will probably not cease at once, but will reverberate for some time in the various neuronal loops within the assembly[13,14]. Thus, ignition and reverberation appear to be important processes occurring in strongly connected cell assemblies.

Words May be Organized in the Cortex as Strongly Connected Cell Assemblies

If Hebb is correct, simultaneous neuronal activity should be the basic brain principle underlying the formation of cortical representations (cell assemblies). What would this mean for language representation and processing?

If a word is articulated by the infant, neuronal activity controlling articulatory movements is present in the inferior frontal lobe. In addition, neurons in auditory cortices in the superior temporal lobe will be stimulated by the self-produced acoustic signal. If I talk, I also hear myself talking and this necessarily leads to simultaneous neuronal activity in inferior frontal and superior temporal cortices (Broca's and Wernicke's areas). Therefore, in this case Hebb would advocate the Freudian opinion rejecting separate cortical representations of articulatory programs and sound patterns, and emphasizing that cell assemblies distributed over motor and sensory regions should form the neuronal counterpart of word forms[15-17]. Figure 4 presents a sketch of such a perisylvian assembly. Although the existence of such assemblies cannot be proven in humans for ethical reasons, the recent discovery of «mirror neurons» in monkeys' frontal lobes that fire in relation to both hand movements and perceptions of such movements appear to support the view that motor and sensory patterns are not separately stored in cortex but are, instead, bound together in sensory-motor cell assemblies[18].

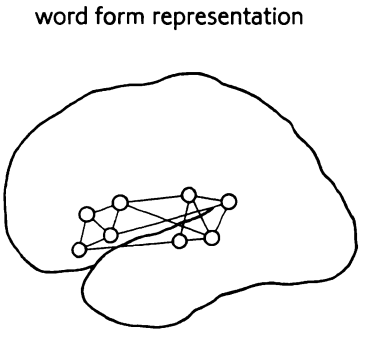

Figure 4: The cell assembly representing a phonological word form may be distributed over perisylvian areas. Circles represent local neuron clusters and lines represent bidirectional fiber bundles between such clusters. The connections are assumed to have strengthened because of correlated activity of neurons during articulation of the word form.

How would the meaning of words be stored in cortex? Associative learning is probably one of the important processes that may occur during acquisition of word meanings. A certain word may frequently be heard when a certain object is being visually perceived, or when the language-learning infant performs certain actions, or when it smells a certain smell, hears certain sounds or has some other perceptions. Therefore, when word forms become meaningful neurons in the perisylvian language areas and neurons located outside these areas, probably in various sensory and motor cortices and also in higher association cortices, are activated at the same time. According to Hebb, these neurons will strengthen their mutual connections and will develop into a cell assembly that comprises neurons in the language areas and outside.

So far, it appears that, from a modern perspective, Freud's approach to language representation was correct. However, not all words are the same, and for certain word classes the Freudian assumptions are most likely incorrect[7]. There are, for example, words with highly abstract meaning

that primarily serve a grammatical function. For these grammatical function words (including pronouns, articles, auxiliary verbs, conjunctions etc.) a representation in widely distributed cell assemblies appears unlikely, because for these words there is no strong correlation between the occurrences of the word form and non-linguistic stimuli or actions. Therefore, grammatical function words should be cortically represented by cell assemblies restricted to the perisylvian areas.

It is well-known that language is localized to the left hemisphere. However, the Hebbian approach suggests that laterality of language is not complete but gradual. If I hear myself say a word, neurons in both hemispheres are necessarily activated at the same time and, according to the associative learning principle, the co-activated neurons in both hemispheres should become part of the assembly representing the word form[19]. Laterality of language may therefore mean that more neurons in the left hemisphere are included in the assemblies than neurons in the right hemisphere. If word meanings are being associated with word forms, the lateralized assembly representing the word form is probably activated together with neurons in both hemispheres, because the perception of a visual stimulus (or the execution of motor programs) will most likely lead to activation of similar numbers of neurons in both hemispheres. Therefore, meaning association should reduce the laterality of word representations. Cell assemblies representing nouns or verbs and other so-called «content words» should be less strongly lateralized to the left than assemblies representing grammatical function words [7,20].

More fine-grained word class-distinctions are desirable based on the Hebbian approach. Some words refer to objects that can be visually perceived, others refer to actions that are usually performed by the own body, and even other words refer to sounds, tastes, somatosensory perceptions etc. According to the modality through which meaning-related information is being transmitted, these word categories can be called «visual words», «motor words», and so on. If Hebb is correct, the cortical distribution of the assembly is a consequence of simultaneous activity occurring in different areas. This implies that a word frequently perceived together with certain visual stimuli (a likely event during learning of words referring to objects) has a cortical assembly quite different from the assembly representing a motor word (which may frequently co-occur with certain movements of the own body). Most nouns with well-imaginable meaning probably are visual words whose assemblies include additional neurons in visual cortices, whereas many action verbs are motor words whose assemblies may include additional neurons in motor cortices, and some nouns, such as tool names, may be considered a mixed category (motor and visual) from this point of view[21]. These modality-distinctions are, however, not the only ones suggested by the Hebbian approach. Because of the somatotopic organization of the motor cortex, words referring to foot movements (to kick) should include neurons in more dorsal motor cortices than words referring to hand movements (to write), and «semantic neurons» of words related to movements involving only a few muscles (to knock) may have a more narrow localization compared to those of words related to complex body movements (to caress). Similar more fine-grained distinctions are, of course, possible for visual words[21,22] and for words whose semantics are anchored in other modalities.

To make these ideas more plastic, Figure 5 presents sketches of possible cortical counterpart of function words, motor words and visual words, respectively. In addition to differences in the language-dominant left hemisphere, a strong degree of laterality can be assumed for function word assemblies and a reduced laterality degree for the other assembly types.

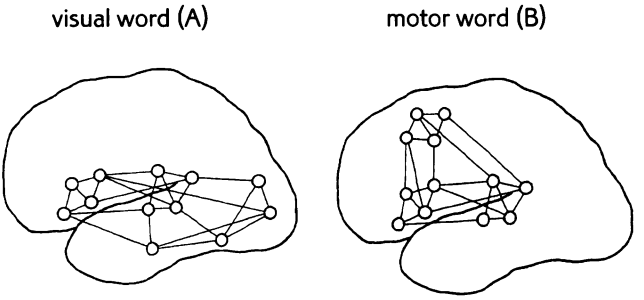

Figure 5: Grammatical function words (pronouns, articles etc.), and words referring to objects and actions may have different neuronal counterparts. A function word may be cortically represented by a perisylvian assembly (see Fig. 4). Words referring to objects usually perceived visually («visual words») may be organized in assemblies distributed over perisylvian and additional visual cortices (A), and words that usually refer to movements of the own body («motor words») may be organized in assemblies distributed over perisylvian and additional motor cortices (B). Many (but not all) concrete nouns are visual words and many action verbs are motor words.

Processing of Different Word Categories Involves Different Cortical Areas

Starting with the considerations offered by Freud[15], there were numerous studies investigating language deficits arising from lesions outside the perisylvian language areas, some of which proved that word categories were selectively affected by lesions in areas outside the perisylvian regions[21-26]. This lesion evidence can, in part, be interpreted as empirical support for the Hebbian perspective outlined above[7,27]. However, the Hebbian ideas can also be tested in psychophysiological investigations of word processing in the intact human brain. Physiological studies can use various imaging techniques based either on direct measures of activity signs caused by electrophysiological activity in neurons (electroencephalography (EEG), magnetoencephalography (MEG), event-related potentials (ERP)), or on indirect measures of metabolic changes probably related to neuronal activity (positron emission tomography (PET), functional magnetic resonance imaging (fMRI)).

Electrocortical differences between content and function words have been found by several ERP studies[28-31]. A finding which was present in all studies - or at least in those using large electrode arrays (20, sometimes 64 and more electrodes) - was the following: Function words led to lateralized event- related potentials, whereas the potentials caused by presentation of content words were more symmetrical over the hemispheres. This is consistent with the idea

of lateralized assemblies representing function words and less lateralized assemblies underlying processing of content words[27].

Numerous metabolic imaging studies have looked at processing of nouns and verbs. In most of these studies, the so-called «verb generation task» was used, that is, subjects were required to say aloud (or think of silently) a verb semantically related to a noun presented acoustically or visually. The brain activity pattern obtained during verb generation was usually compared to the activity pattern while reading or repeating (silently or aloud) the same nouns. Results of these experiments are highly heterogeneous. However, taken together, enhanced metabolism during verb generation was found not only in Broca's and Wernicke's areas, but, in addition, in adjacent prefrontal and temporal areas and sometimes in both hemispheres[32-35]. This may be taken as evidence that verb processing involves perisylvian language areas and cortices outside. However, it has been argued that verb generation and repeating nouns are tasks that vary not only with regard to the words being relevant. Therefore, other psychological processes (arousal, attention, search and judgment processes etc.) may be related to the observed metabolic differences.

In studies of electrocortical noun/verb differences in the intact brain, both word types were presented in the same tasks, for example lexical decision, where subjects have to decide whether letter strings are meaningful words or meaningless pseudowords. Such studies revealed word category differences in event-related potentials (ERPs)[36,37]. After submitting data to current source density analysis, a method for enhancing the contribution of local cortical generators to the electrocortical signal, event-related potentials revealed stronger signs of cortical activity at central recording sites —over motor and premotor cortices— when motor words (action verbs) were being processes, whereas activity signs were enhanced at posterior recording sites —over visual cortices— when visual words (nouns with well-imaginable meaning) were processed. This pattern of results provides support for the Hebbian view that visual and motor words are represented and processed differently in the cortex[27].

One may argue, however, that nouns and verbs do not only differ with regard to their semantic properties, they also belong to different lexical categories. The physiological differences observed may, therefore, be related to lexical rather than semantic properties. This is certainly an important point, however, the assumption of the semantic difference being relevant can explain why differences in electrocortical activity between action verbs and imaginable nouns were present over visual and motor cortices, and this speaks in favor of the present interpretation. Furthermore, more recent imaging work investigated differences in brain metabolism between animal names and tools names which led to somewhat similar results. Most animal names belong to the category of visual words because their meaning is learned (by most individuals in the western culture) based on input through the visual modality, whereas tool names probably elicit not only visual associations but, in addition, remind subjects of the body movements involved when using the tools. Processing of tool names in a naming task led to activation of premotor cortices in frontal lobe, whereas processing of animal names in the same task enhanced metabolism in visual cortices in the occipital lobe[38]. (In the case of tool naming, an additional focus of activity enhancement was

present more posteriorly in the middle temporal gyrus which may be related to associations of visually perceived movements related to tool usage or to imagination of their shapes[24,38].) These data provide additional evidence for the view that words with motor and visual associations are represented differently in the intact brain, and that they involve areas outside the classical language areas that reflect semantic word properties.

Reverberation of Neuronal Activity in Cell Assemblies Representing Words May be Reflected in High-frequency Cortical Responses

The cell assembly concept is a tool for theorizing about cortical representations. It is difficult to actually prove that cell assemblies exist in cortex, and it is even more difficult to provide a proof that they are the basis of cognitive processing, as suggested by Hebb. However, recent evidence from neurophysiology demonstrates that multiple neurons in various cortical areas can exhibit synchronous rhythmic activity patterns in a rather high frequency range, that is around 30 Hz and above[39]. High-frequency activity is stimulus-specific, that is, particular neuron sets may synchronize their rhythmic responses when a particular visual stimulus is being presented, whereas other neurons become synchronized when a different stimulus is shown. This kind of synchrony in cortex is only possible if cortico-cortical fibers are intact, although subcortical connections may play an additional role in synchronizing cortical responses[40]. Stimulus-specific synchronous high-frequency activity in cortex is difficult to explain without using the cell assembly concept, and may, therefore, be considered as evidence for this notion. If reverberation of neuronal activity in cortical cell assemblies causes enhancement of well-timed high-frequency responses in these neurons, some of the ideas formulated above can be experimentally tested. For non-invasive recordings of such responses, EEG- and MEG-mapping are necessary, because only these recording techniques have the fine-grained temporal resolution in the millisecond range necessary for recording high-frequency activity in cortex.

Assuming that reverberation of neuronal activity in cell assemblies is visible in high-frequency responses one would predict that these responses are stronger when a cognitive representation is being activated compared to a state in which no such representation is being accessed. According to the Hebbian view, words are represented in cortical assemblies while meaningless pseudowords, such as «noom», lack a cortical representation because they have never been learned. This predicts stronger high-frequency cortical responses to words compared to pseudowords («moon» vs. «noom»). In a series of experiments, we obtained empirical support for this prediction[41-44]. EEG and MEG responses to words and pseudowords presented acoustically or visually consistently revealed differences in spectral responses in the 30 Hz-range. Importantly, no similar differences were present in lower parts of the spectrum (alpha-band around 10 Hz) or in the higher spectrum, where muscle activity would be most strongly visible. Differences in high-frequency responses were most pronounced and significant at recording sites above the language

cortices in the left hemisphere of right-handed experiment participants. These results are consistent with the view that cell assemblies exhibiting well-timed reverberation of neuronal activity with a predominant frequency around 30 Hz become active when words are being processed but fail to ignite after presentation of meaningless pseudowords. Similar dynamics of 30 Hz-responses have recently been reported from a comparison of meaningful visual Gestalts vs. physically similar but meaningless visual stimuli that are not perceived as a coherent gestalt[45]. All of these findings support the view that meaningful elements (words, gestalts) —but not similar meaningless stimuli— activate cell assemblies generating 30 Hz-activity.

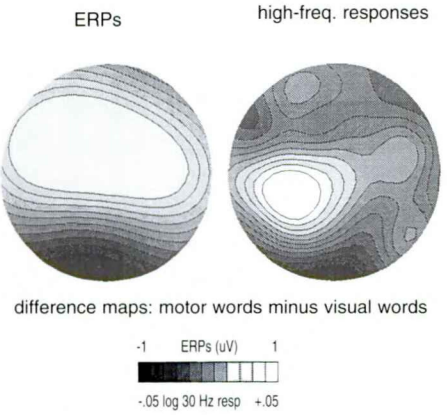

Figure 6: Processing of motor words (verbs) and visual words (nouns) is accompanied by significantly different electrocortical responses. Difference maps (nouns minus verbs) are shown. Large circles represent the head seen from above (anterior is up). Verbs elicit stronger signs of activity over motor cortices of both hemispheres, whereas nouns elicit stronger signs of activity over visual cortices. Differential topographies of event-related potencials are compared to evoked spectral responses in the frequency range 25-35 Hz. Adopted from Ref. 27.

The Hebbian cell assembly perspective would, however, allow for even more specific predictions. For example, processing of words with different meanings, such as motor and visual words, should not only induce different global activity in motor and visual cortices, but, in addition, there should be a specific change of high-frequency activity in the same cortical areas. This prediction was tested in a recent experiment again using action verbs and nouns with well-imaginable visual meaning[44]. Significant differences in 30 Hz EEG responses were present over motor cortices, and additional differences were seen over occipital visual areas (recording sites C3/C4 vs. O1/O2 of the international 10/20-system). High-frequency responses to motor words were stronger over motor cortices, whereas they were stronger over visual cortices for visual words. This provides another piece of evidence for the Hebbian perspective on language representation in the brain.

It may, however, be claimed that differential high-frequency responses are not necessarily a sign of cell assembly ignition and reverberation of neuronal activity therein. More global neuron loops may also generate high-frequency activity, as has been made evident by recordings in

arthropods[46] and in the retina of vertebrates[47]. One may, therefore, claim that differential high-frequency cortical responses can be a consequence of various cortical activation processes. However, it is important to note that there is at all any difference between high-frequency responses to physically similar meaningful and meaningless elements, to words and pseudowords, to gestalts and pseudogestalts, to nouns and verbs. This can only be explained if high-frequency responses are interpreted as a consequence of the activation of cortical representations that depend on the meaning (or Gestalt properties) of stimuli. Furthermore, if dynamics in 30 Hz responses were a sign of global changes of cortical activity in cortical areas, their spatio-temporal properties should be the same as for other global activity indicators such as event-related potentials. This, however, is clearly not the case[27]. At this point, more experimental work is necessary in order to decide whether 30 Hz-responses actually reflect fast reverberation of neuronal activity within cell assemblies or reverberation processes caused by activation of cognitive cortical representations (ignition of cell assemblies) but involving additional neurons outside the representation (assembly).

The Hebbian Approach to Language Representation in the Brain May Provide Biological Answers to Additional Questions from Language Science

These results provide support for the claim that words of different semantic classes are represented in cell assemblies with different cortical distributions. All of these assemblies appear to have some of their neurons located in the perisylvian language areas of Broca and Wernicke, and some words may be represented by assemblies including additional neurons outside the language areas, and possibly in both hemispheres. Semantic word properties appear to be reflected in the additional areas becoming relevant. Evidence for different distributions of cell assemblies can be obtained from global activity measures such as provided by metabolic or neurophysiological imaging techniques, and, in addition, important clues about reverberating neuronal activity in cell assemblies (or related to cell assembly activation) may come from investigations of high-frequency cortical responses recorded in the EEG and MEG.

It should be emphasized that the Hebbian model put forward here is related to large-scale neuronal theories of language that are based on Hebbian associationist learning principles[16,22,48,49]. All these models have in common that 1) widely distributed neuron sets in cortex (and additional subcortical structures) are assumed to be the substrate of language processing, and that 2) such assemblies are assumed to form as a consequence of associative learning. Distinctive features of the approach discussed above include the assumptions (i) that processing of an individual word (and of any meaningful stimulus) does not only lead to the activation of cortical areas, but rather to the activation of a distinct neuron set, a cell assembly representing the individual meaningful element, (ii) that phonological, semantic and other features of a word are bound together in its neuronal representation so that stimulation of the assembly leads to almost

simultaneous activation of the word representation implying simultaneous access to all of its features on the cognitive level, (iii) that two distinct processes, ignition and reverberation of neuronal activity, follow stimulation of an assembly, and (iv) that right-hemispheric processes are involved in word processing and that right-hemispheric processes are different for words of different classes. Claim (i) is primarily motivated by theoretical considerations, but the finding that there are cortical neurons specifically activated by low-frequency words provides support for this assumption [50]. Claim (ii) is supported by early electrocortical differences between vocabulary types which were present as early as around 200 ms after stimulus onset not only over perisylvian areas, but, in addition, over motor and visual areas probably involved in processing of word meanings. Assumption (iii) is consistent with the finding that word-class differences in event-related potentials (possibly indicating differences in ignition) occurred shortly after stimulus onset (around 200 ms) whereas dynamics in high-frequency responses (possibly related to reverberation) usually occurred only later. Finally, assumption (iv) is supported by studies evidencing a) different degrees of laterality of electrocortical activity elicited by words of different classes and b) word class-specific activity differences in the right hemisphere.

From a linguistic point of view, however, the question addressed above - the question of the cortical organization of words of different classes - is only a very basic one, and it is absolutely clear that neurobiological models cannot, at this point, answer complex questions about the brain mechanisms that govern the sequencing of words in sentences and the sequencing of speech acts in complex dialogues. Whereas some sequencing rules may be biologically realized as connections between cell assemblies that form based on associative learning principles, genetically programmed information may be necessary for other syntactic mechanisms [51]. Specification of these mechanisms in terms of neurons and cell assemblies appears to be one of the most exciting goals in cognitive neuroscience.

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I think this talk goes very well with the talk we had this morning on the metabolic data and word recognition and so there will be no confusion between my own remarks and my views of this kind of work.

I think that it is absolutely essential that people do research on single word items and that you can learn things, so that is not an issue. I was struck by all three of the talks today for the fact that we all felt obliged to mention Wernicke someplace in the first moment. I think this is becoming a tradition in the whole area. If you go to neuroanatomy lectures somewhere within the first two paragraphs there will be a references to the **Great** Cajal, who was always referred to as the **Great** Cajal, so we are developing the same kind of tradition in neurolinguistic research.

I think that brain images studies, the PET and SPECT data, we saw this morning and the electrophysiological data, are very valuable because they are providing inside into areas where we had functional behavioral data, but where we couldn't tell very much about what was going on. For example, we just heard references to split brain studies from which E. Zaidel showed, twenty years or so ago, that the right hemisphere does represent lexical items, at least open class lexical items, very importantly. But we didn't have much of a picture of that other than what you would get from behavioral studies of split brain patients. Another finding of Zaidel's was that the right hemisphere, when it processed words, did not processed them phonologically in the same sense that the left hemisphere does. That is, the right hemisphere cannot do segmentation. So right hemispheres cannot rhyme, *run, fun, sun, tan*, because the act of rhyming requires segmentation. Rather Zaidel would suggest that the right hemisphere represents words as some kind of acoustic stock car holistically, so that this would be true of phonology or morphology, so the word *dog* would be represented independently of the word *dogs* plural. So I think that works that we heard reported today on semantics and phonology are very important because they allow us to follow up in a much more clear and precise way on these earlier behavioral data.

I thought particularly with the issue of phonology that perhaps your data are ambiguous in a way that this morning's data were not. Let me ask you just a factual question, just to get this correct.

— M. L. Kean— In the right hemisphere you found no difference between words and non words, the *moon noom* type example?

—F. Pulvermüller— Not in the high frequency responses area.

— M. L. Kean— It seems to me that one could argue that the initial responses you get maybe were involved with word recognition, that is recognition of a word as an existing word and that your subsequent patterns of activity may reflect post access processes involved in, that follow automatically once you recognize the word as a word, and some of those post access processes are phonological as well as syntactic, so I just raise that as a possibility to what I would want to look at more closely.

Another question I have is, and perhaps it sounds silly, but it has to do with the notion of action words and motor words, and how distributed representations are. Because there are words I would think of (this is a totally intuitive experiment) as being clearly action words but they are not actions I can perform as a human being, for example flying. I may fly in my dreams but I certainly don't do it like this, is more like levitating if you examine my dream states. But flying or galloping. You know horses gallop, I can't gallop, at least not in the sense that horses can, maybe someone can use the term metaphorically, so I worry to some extent about making intuitive semantic distinctions such as action word - non action word obtained in anatomical areas in the human brain, because galloping and trotting, things horses do, are actions I can't do, but I'm sure I represent those notions richly because I like to ride horses, I have ridden horses all my life.

The other issue that concerns me is in the same sort of area, and is the issue of polysemy. I am not quite sure how you deal with that. If you believe David Swinney for example — a very subtle psycholinguist— when one hears a polysemous word, initially all interpretations of the word are activated and then the appropriate representation is selected from the set. And this crosses not only motor, visual, tactile but also categories noun/verb, so a word like *run* is a verb and it would be a motor thing perhaps but we also have *run* as in *running water* which isn't a motor thing, we also have *run* as a noun, like *I got a run in my stocking*, or a *show has a run on Broadway*, so you have this wide range of meanings, crossing the visual motor domain and also crossing the noun/verb domain, so somewhere in the time course of processing what one has to do is activate the lexical item and then make the selection. So I was wondering where your work was leading you in that domain.

The final comment I would like to make has to do with language acquisition. Because I think language acquisition can be highly informative in terms of helping us formulate questions for neurolinguistic research with adults. As I mentioned this morning, it seems to me initially from reading your paper that you would predict that it would be harder for a blind child to learn lexical items or might be slower. That was my initial reaction, you have told me that I was wrong, but that was my initial reaction.

The other issue I would raise is the relation between the linguistic environment of the child and what comes to be represented. And here I am thinking of work by Lyla Gleitment along with

Susan Goldenmedow and Hidy Feltman on the acquisition of language without a model. These are deaf children whose parents do not sign at all, in fact the parents of these children are told: «Do not sign to your child because signing will weaken your child's mental growth», an absolute nonsense, but there are parents that believe this quite strongly. So you have a bunch of children, who can be studied, who are at the age of language acquisition, and who have no model, and what is particularly interesting about these children, first of all is that they develop their own idiosyncratic sign languages. That is, the drive to have language is overwhelming. And they go through the same stages of acquisition as normal children do and they have the same patterns. So if they want Mummy to throw a ball they say *Mummy throw* not *throw mummy* which would be inappropriate. So their pattern of syntactic development is very similar to that of a hearing child but these children have no model.

Linguistic experience *per se* involves how we learn words and how we represent them and where linguistic experience in actual acquisition varies upon the domain of the vocabulary type and I think that is an issue that is worth pursuing if one is going to have differential types of representation or pursue your lines of work.

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