NEUROBIOLOGY OF LANGUAGE AND SPEECH

Victoria A. Fromkin

University of California, Los Angeles

ABSTRACT

The interest in the neurobiology of language and speech goes back at least 3000 years. Its recent resurgence reflects the concern for explanation as well as description. Much current research utilizes the new technologies for studying brain/behavior relationships such as Magnetic Resonance Imaging (MRI) Positron Emission Tomography (PET), and Event Related (Brain) Potentials (ERP). This symposium discusses different aspects of this question.

BACKGROUND

The interest in the neurobiology of language and speech and in the brain/behavior interface goes back at least 3000 years.[1] Its recent resurgence reflects the concern among linguists and phoneticians in explanation as well as description. We are no longer satisfied with knowing that the obicularis oris is activated to a greater extent in the production of an initial than a final /p/ [2] although such questions remain important in our understanding of the phonetic realization of phonological units; in addition, we seek answers to questions such as those raised by Chomsky in 1988 [3]: 'What are the physical mechanisms that serve as the material basis for (the) system of (linguistic knowledge) and for the use of this knowledge?' (p 3) 'In the study of language we proceed abstractly, at the level of mind, and we also hope to be able to gain understanding of how the entities constructed at this abstract level and their properties and the principles that govern them can be accounted for in terms of properties of the brain.' (p 8)

Although we do not have any final answers to the question of the neural structures underlying linguistic units such as sentences, phrases, words, or phonological or phonetic segments, the new technologies for studying brain/behavior relationships such as Magnetic Resonance Imaging (MRI) Positron Emission Tomography (PET), and Event Related (Brain) Potentials (ERP) are beginning to provide some answers. In addition, the utilization of these new technologies to the study of language and speech disorders following focal damage to the brain, contributes to our understanding of the neurobiology of normal language and speech.

That this is hardly a new issue is shown by the fact that in the 135th Psalm, one find an implicit recognition of the left brain / language interface (although contralateral brain function was of course not understood). The verse states: "If I will forget thee, Jerusalem, let my right hand die -- let my tongue cleave to the roof of my mouth."

In the New Testament, St. Luke reports that Zacharias could not speak but could write, predating the modern observations of the independence of linguistic components by two millennia.

As pointed out in the Whitaker contribution to this session, observations of language loss with intact general

intelligence are found in the medical records written on papyrus in 1700 B.C.E. by Egyptian surgeons, long before the philosophers of ancient Greece speculated about the brain/mind relationships. Although neither Plato nor Aristotle recognized the brain's crucial function in cognition or memory as shown by Aristotle's suggestion that the brain is a cold sponge whose function is to cool the blood, in the same period , the Graeco-Roman physicians' Hippocratic Treatises (written from 400 BCE to 135 CE) reveal their understanding of the role of the brain in noting that language and speech disorders result from cerebral trauma or brain disease and that loss of speech often occurred simultaneously with paralysis of the right side of the body. They also showed an understanding of the separation of linguistic competence and performance in their observation that language loss may occur without the loss of speech and vice versa. [4]

Other writers and scholars of the ancient classical world and the mediaeval period provide us with a wealth of information on aphasia -- the loss of distinct linguistic abilities -- with a preservation of nonlinguistic cognitive functions, as well as differential impairment and preservation of different linguistic abilities. Over 2000 years ago Valerius Maximus and Pliny described the Athenian scholar who in the words of Pliny "...with the stroke of a stone, fell presently to forget his letters only, and could read no more; otherwise his memory served him well enough." [1]

Numerous clinical descriptions of patients with language deficits and preserved non- linguistic cognitive systems were published from the 15th to the 18th century. [5]

Differential breakdown of language and components of language were reported in detail throughout the 16th to the 19th century. Such descriptive reports strongly support current day views of the modularity of mind, the independence of language from other cognitive systems and general intelligence, and also, the modularity of the components of the mental grammar itself.

Whitaker's discussion in this symposium on the importance of, the pitfalls, and gaps in the history of neurolinguistics from 1600 to 1900 provides new insights regarding this important issue. I will therefore only mention the two 19th C names probably most familiar to linguists and phoneticians -- Broca [6] and Wernicke [7]. Broca's seminal paper of 1861 reported on the specific role of the left hemisphere in relation to language localized brain areas..

In 1874, Wernicke [7] provided further evidence when he pointed out that damage in the posterior portion of the left temporal lobe results in a different form of language breakdown than that occurring after damage to the frontal cortex.

The fact that focal injuries to different parts of the brain not only lead to selective cognitive disorders, but to damage of distinct components of language or of specific linguistic processing mechanisms provide a major reason for the linguistic interest in aphasia.

Blumstein's contribution to this symposium draws on the earlier findings of Broca and Wernicke and on all the research which has followed. She discusses specific phonological and phonetic deficits and the linguistic and non-linguistic basis for these in reference to anterior and posterior lesions.

Jakobson's Legacy

The years which followed Broca's and Wernicke's discoveries stimulated neurologists throughout the world such as Broadbent [8] and Bastian [9] in Britain, Pick [10] and Salomon [11] in Germany, Moutier [12] in France, and Hughling Jackson [13,14] in the US, among others, to apply linguistic analyses to aphasia data. But Roman Jakobson [15,16, 17, 18,] was the first linguist to apply linguistic theory to aphasia research.

Following up on the insights of Baudouin de Courtenay in 1895 and Ferdinand de Saussure in 1879 [19] who had expressed the belief that a study of language pathology could contribute to linguistics, Jakobson also stressed the other side of the coin, the contribution of linguistics to the study of aphasia, stating that "any description and classification of aphasic syndromes must begin with the question of what aspects of language are impaired". [17] He despaired over the fact that" the linguist's contribution to the investigation of aphasia is still ignored" and also believed that "Linguists are also responsible for the delay in undertaking a joint inquiry into aphasia."

Jakobson would have been pleased to have seen the developments that have taken place in the last number of years, which led to the holding of this session on the neurobiology of language.

His notion of the hierarchical organization of linguistic entities proposed in his early works on phonology, found its expression in the theory of markedness discussed in relation to phonological paraphasias by Kean in this symposium. Kean also provides strong evidence for the correctness of Jakobson's view of how linguistic theory can contribute to our understanding of aphasia. [20, 21] Her paper, as well as Blumstein's, provides rich evidence for the insights provided by linguistic theory.

Except for Jakobson, few linguists followed up the early interest in linguistics by neurologists who drew on linguistic concepts in their investigations of aphasia. The first linguist to follow Jakobson's lead was Blumstein [23] who applied his theories of distinctive features and markedness to an experimental investigation of aphasic phonemic errors and who further emphasized Jakobson's view that an analysis of aphasic errors can contribute to phonological theory, itself. In her paper at this congress she, as well as Kean, provides additional evidence in support of her original finding that in aphasic speech errors (like normal errors) the direction of substitution is from marked features (nasal /n/) to unmarked (non-nasal /d/).

Blumstein and Kean show that evidence from aphasia presents a partial answer to whether the mental grammar, that is, the representation of linguistic knowledge in the mind and brain, is itself decomposed into components like those projected by linguists on the basis of language evidence alone.

Furthermore, as Blumstein's paper points out, speech deficits in aphasia may be due to either linguistic or non-linguistic causes, taking different forms in the two cases.

Early views of aphasia tended to treat the different syndromes as either expressive or comprehension disorders. Whitaker, in his paper, points out that Broca was concerned only with speech production since comprehension was considered to be out of the province of

'real science', i.e. the province of the philosophers and others concerned with the mind. (How reminiscent of the behaviorist period in American linguistics.) The early view that agrammatism was a disorder of speech production with intact speech comprehension was upset in the 1970's when controlled experimental studies showed that when comprehension depends on the syntactic structure of sentences, syntactic comprehension deficits -- asyntactic comprehension -- also arise in these patients. [24,25,26,27,28]

This suggests that a syntactic representation or processing deficit was involved, again supporting the notion of distinct and possibly independent components.

SPEECH, SIGN, AND LANGUAGE

Aphasia was originally seen as a problem in speech -- production in relation to Broca's aphasia, and comprehension/perception in relation to Wernicke's aphasia. However, both Blumstein's and Kean's papers make clear that many speech problems may be more properly viewed as language, not speech disorders.

Perhaps the most telling and dramatic findings on the brain / language / speech relationship is revealed by the research on sign language conducted by Bellugi and her colleagues [29]. The linguistic study of sign language over the last 25 years has already revealed that these languages of the deaf have all the crucial properties common to all spoken languages, including highly abstract underlying grammatical and formal principles.

Since the same abstract linguistic principles underlie all human languages -- spoken or signed -- regardless of the motor and perceptual mechanisms which are used in their expression, it is not surprising that deaf patients show aphasia for sign language similar to the language breakdown in hearing aphasics following damage to the left hemisphere.

The left cerebral hemisphere is not dominant for speech but for language, the cognitive system underlying both speech and sign. Hearing and speech are not necessary for the development of left hemispheric specialization for language.

Furthermore, while deaf patients with focal lesions show marked sign language deficits, they can correctly process non-language visual-spatial relationships. The left cerebral hemisphere is thus not dominant for speech, as had been suggested, but for language, the cognitive system underlying both speech and sign. Hearing and speech are not necessary for the development of left hemispheric specialization for language.

This has been a crucial point in determining that the left hemisphere specialization in language acquisition is not due to its capacity for fine auditory analysis, but for language analysis per se.

CT, PET, MRI, AND ERP STUDIES

Aphasia studies have been crucial in the investigation of the brain/language-speech relationship. The advent and development of new imaging technologies such as computerized tomography (CT), Magnetic Resonance Imaging (MRI), Positron Emission Tomography, and Event Related Brain Potential (ERP) studies now make possible greater access to the macroscopic neuroanatomy and neuropathology of living humans. [30] The first use of these techniques in studies of brain and language paralleled the aphasia studies approach, i.e. the 'lesion method'. As stated by the Damasios, "The essence of the lesion method is the establishment of a correlation between a circumscribed region of damaged brain and changes in some aspect of an experimentally controlled behavioral performance. Given a preexisting theory about the operation of the normal brain and how it would mediate the performance of (a task such as speech production or comprehension) the lesion (the area of brain damage) can be seen as a probe to test the validity of the theories." (p 8) [11]

Through the use of these techniques we have a much better understanding of the localization of function and of the neuroanatomy underlying language and speech.

PET allows us to look at the normal (as well as the disordered) brain in vivo as shown by blood flow. Similarly, functional MRI's and ERPs allow one to see what is going on in the brain during various task performances or response to different kinds of stimuli. ERP experiments study scalp electrical activity as recorded from electrodes placed on the scalp according to a universally agreed on set of positions following different stimuli presented to the subjects.

A number of PET experiments have examined phonological processing. [31] Despite the sanguine view of all such studies, we should keep in mind Poepple's [26] caveat regarding the many problems which remain in the interpretation of the data. He points out that a comparison of PET studies shows that because of great variation across subjects and tasks, we can not "attribute phonetic/phonological processes to a specific region of the brain". This does not mean there may not be such a region, (but see Blumstein's conclusion that "anterior as well as posterior brain structures are implicated in the auditory processing of speech.") It does mean that while we welcome the new technology, we cannot abandon other traditional approaches and, as is obvious, the use of all new technological tools should be motivated by linguistic theory.

We are reminded of Sapir's warning in 1925 [32] "Mechanical and other detached methods of studying the phonetic elements of speech are, of course, of considerable value, but they have sometimes the undesirable effect of obscuring the essential facts of speech-sound psychology." At the same time, as shown in Blumstein's paper, instrumental acoustic analysis is vital in trying to uncover impairments in the speech of aphasic patients which are not easily perceivable by the human ear.

Furthermore, the ERP studies now being conducted are proving to provide important evidence regarding both representation and processing. Hagoort and Brown's paper in this symposium provides an excellent overview of what is involved in such studies. They claim that this new technique provides a real-time neurophysiological measure of speech processing with temporal resolution superior to other imaging techniques

Their findings of different neurophysiological responses to semantic and syntactic processing replicates another study by Neville and co-researchers [33]

Using a different experimental task, Neville's group found that syntactically well-formed but semantically anomalous sentences produced a pattern of brain activity (ERPs) that is distinct in timing and distribution from the patterns elicited by syntactically deviant sentences, and further, that different types of syntactic

deviance produced distinct ERP patterns as illustrated in the examples below:

1. #The man admired Don's headache of the landscape.
2. *The man admired Don's of sketch the landscape..
3. *What$_i$ was [$_{NP}$ a sketch of t_i] admired by the man?

As in Hagoort and Brown's studies, the semantic anomalies sentences such as 1. produced a negative potential, N400, that was bilaterally distributed and was largest over posterior regions. The phrase structure violations such as in 2. and 3 enhanced the N125 response over anterior regions of the left hemisphere, and elicited a negative response (300-500 msec) over temporal and parietal regions of the left hemisphere. The specific types of syntactic violations such as specificity constraints, and subjacency constraints elicited distinct timing and distribution responses.

They conclude: "the distinct timing and distribution of these effects provide biological support for theories that distinguish between these types of grammatical rules and constraints and more generally for the proposal that semantic and grammatical processes are distinct subsystems within the language faculty."

CONCLUSIONS

The four papers presented in this session aim at illustrating the importance of the research on the brain /language /speech interface. Whether one uses the new technologies and experimental techniques to investigate the speech production and comprehension of normals or of aphasics we are beginning to gain a better understanding of the neurobiology of language and speech.

REFERENCES

[1] Benton, Arthur L. and Robert J. Joynt (1960) Early descriptions of aphasia. *Archives of neurology* 3.109/205-126/222

[2] Fromkin, V. A. (1966) Neuro-muscular specification of linguistics units. *Language and Speech* 15.219-242

[3} Chomsky, N. (1988) *Language and Problems of Knowledge: The Managua Lectures.* Cambridge, Mass. MIT Press.

[4] Breasted,J.H. (1930) *The Edwin Smith Surgical Papyrus.* Chicago: University of Chicago Press

[5] Clarke,E. and O'Malley, C.D. (1968) *The human brain and spinal cord: A Historical study illustrated by writings from antiquity to the twentieth century.* Oxford:Sanford Publications

[6] Broca, Paul (1861) Nouvelle observation d'aphemie produite par une lesion de la moitie posterieure des deuxieme et troisieme circumvolutions frontales. *Bulletin de la Societe Anatomique de Paris* 3.398-407

[7] Wernicke, C. (1874) The aphasic symptom complex:a psychological study on a neurological basis. Kohn and Weigert, Breslau reprinted in R.S. Cohen and M.W. Wartofsky (eds) *Boston Studies in the Philosophy of Science, vol 4.* Reidel, Boston

[8] Broadbent,W.H. (1879) A case of peculiar affection of speech, with commentary *Brain 1,* 484-503

[9] Bastian,C. (1887) On different kinds of aphasia with special reference to their classification and ultimate pathology. *British Medical Journal* 2, 931-6

[10] Pick,A. 1913 *Die Agrammatischen Sprachstorungen*. Springer, Berlin

[11] Salomon, E. 1914 Motorische Aphasie mit Agrammtismus und Sensorischagrammatischen Storungen. *Monatschrift fur Psychiatrie und Neurologie* 35, 181-208, 216-75

[12] Moutier, F. 1908 *L'aphasie de Broca* Paris:Steinheil

[13] Jackson, J.H. (1874) On the nature of the duality of the brain. in . J. Taylor (ed.) *Selectged Writings of John Hughlings Jackson*/. vol 2. New York: Basic Books

[14] Jackson, J.H. (1878) On affections of speech from disease of the brain. *Brian.* 1.304-30; 2. 203-22; 323-56

[15] Jakobson, R. (1940) *Kindersprache, Aphasie and allgemeine Lautgesetze* Almqvist u. Wilsells, Uppsala. Reprinted as *Child Language, Aphasia, and Phonological Universals* 1968. Mouton, The Hague.

[16] Jakobson, Roman (1955) Aphasia as a linguistic problem. in *On Expressive Language.* edited by H. Werner. Worcester, Mass: Clark University Press,. 69-81

[17] Jakobson, R. (1964) Towards a liguistic typlogy of aphasic impairments. *Disorders of language.* Edited by A.V.S.deReuck and M. O'Connor Boston: Little,Brown 21-41

[18] Jakobson, R. (1970) Toward a linguistic classification of aphasic imnpairments. *Selected Writings II.* The Hague: Mouton.

[19 Saussure, Ferdinand de. (1916) *Cours de linguistique generale*. Paris. Payot.

[20] Kean, Mary Louise 1977 The linguistic interpretation of aphasic syndromes: agrammatism in Broca's aphasia, an example *Cognition 5*, 9-46

[21] Kean, M-L. (Editor) (1985). *Agrammatism* Academic Press, New York

[22] Blumstein, S. (1973) *A Phonological Investigation of Aphasic Speech*. The Hague: Mouton

[23] Caplan, D. and Futter, C. (1986). Assignment of thematic roles by an agrammatic aphasic patient. *Brain and Language* 27. 111-134

[24] Caramazza,A. and E. Zurif (1976) Dissociation of algorithmic and heuristic processes in language comprehension: Evidence from aphasia *Brain and Language* 3, 572-82

[25] Grodzinsky,Y. (1990) *Theoretical perspectives on Language Deficits.* Cambridge, Mass: MIT Press

[26] Linebarger, M., M.F. Schwartz, and E.M. Saffran. (1983) Sensitivity to grammatical structure in so- called agrammatic aphasics.*Cognition*13.361-92

[27] Schwartz, M.R., Linebarger,M.C. and Saffran, E.M. 1985. The status of the syntactic deficit theory of agrammatism in *Agrammatism.* edited by M-L. Kean editor. NY: Academic Press. 83-124.

[28] Zurif,E.B. and Grodzinsky, Y. 1983 Sensitivity to grammatical structure in agrammatism: A reply to Linegarger et al. *Cognition* 15: 207-213

[29] Poizner, H.E., Klima, E. and U. Bellugi. (1987) *What the Hands Reveal About the Brain.* Cambridge, Mass: MIT Press

[30] Damasio,H. & Damasio, A.R. (1989) *Lesion Analysis in Neuropsychology.* Oxford, NY: Oxford University Press

[31] Poeppel, D. (1993) A critical Review of PET Studies of Language. Dept. of Brain and Cognitive Sciences, MIT. Unpublished ms.

[32] Sapir, E. (1925) Sound patterns in language. *Language.* 1. 37-51

[33] Helen Neville, Janet L. Nicol, Andrew Barss, Kenneth I. Forster, and Merrill F. Garrett. 1991. Syntactically Based Sentence Processing Classes: Evidence from Event-Related Brain Potentials, *J of Cognitive Neuroscience.* Vol. 3/.2/ 151-165) in experiments involving event-related potentials or ERP's. Such