Neurolinguistics and linguistic aphasiology

An introduction

David Caplan
Montreal Neurological Institute

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Issues in neurolinguistics and linguistic aphasiology

The terms "neurolinguistics" and "linguistic aphasiology" are new ones, in use for a little over a decade. The areas of study to which they refer, the nature of language breakdown and the relationship between language and the brain, are much older than the term. Indeed, the study of language–brain relationships can be seen as one aspect of the more general study of the relationship between mind and brain (or mind and body) which has occupied Western philosophy since its beginning. The scientific study of language–brain relationships began in the last half of the nineteenth century, and detailed descriptions of language disturbances after brain injury began to be published before the turn of this century. However, despite their distant and recent histories, these fields have recently developed new directions and vigor, and the new terms are appropriate and increasingly popular. An increasing number of scientists from the fields of linguistics, psychology, speech pathology, and neuroscience are beginning to make their primary study the questions of how language is represented and processed in the brain, and how it breaks down after brain injury. Thus, the subject has a life of its own, independent of the disciplines which contribute to it. Techniques and concepts from linguistics, psycholinguistics, artificial intelligence, neuroanatomy, and other sciences are increasingly being applied to what was traditionally a medical preserve, yielding new discoveries about language disorders and their neural determinants which in turn have led to more detailed understanding of language and the brain. In short, while still very dependent upon contributing areas, neurolinguistics and linguistic aphasiology are becoming viable, autonomous areas of study. The new terms both reflect and announce the development of these new areas of study.

This book is designed to provide an introduction to these new areas. We shall trace the history of scientific studies of language breakdown and language–brain relationships from the first scientific paper on the latter subject by Paul Broca in 1861 to contemporary work consisting of computer models, psycholinguistic experiments, and brain stimulation and recording. The central questions to which we shall return, again and again, are how

language breaks down, and how it is represented and processed in the brain. We shall come across fascinating case descriptions of patients, such as individuals who cannot read what they have written; we shall find that electrically stimulating certain brain structures can disturb some language functions while stimulating other structures improves them; we shall consider mathematical analyses of sets of neurons which model some features of human language. It is important, in all this fascinating material, not to lose sight of the central questions we want to try to answer. In this chapter, we shall consider some of these questions, trying to draw the boundaries of this field at least in general terms, and to relate this area of science to other areas, such as linguistics, psychology, and neuroscience.

What do we want to know about language breakdown and the relationship between language and the brain? It has been said that the most important thing a scientist must learn is which questions to ask, and it is certainly true that which questions we ask will determine the type of information we seek and, ultimately, the understanding that we attain. If we are concerned as, for instance, are medical practitioners, about whether various types of patients will recover from disorders affecting language, then we will seek information regarding recovery from different language impairments and from the different diseases of the brain that affect language. We would hope to arrive eventually at the point where we can offer an educated prognosis to a patient. We might not achieve an understanding of what language is and how it is processed, or of the structures and events in the brain which underlie storage and use of language, for that would not be our principal concern. Of course, it may turn out that to answer questions about prognosis, we need to know about the way language is structured and the way it is processed in the brain; or it may turn out that a by-product of our study of recovery from language impairment is some insight into these other issues. But it is also possible that we will not need to concern ourselves with the question of how language is processed and stored in the brain to answer the medical question of prognosis of a language disorder. A decision to pursue the medical question of prognosis may well be the most important decision we make, one which determines what we eventually understand about language–brain relationships. This example – which is not hypothetical, as will be apparent in later chapters – stresses the importance of asking good questions. It also indicates that there are many good questions, and that our choices among them will be determined by our general purpose in approaching the field. Most scientists have found that it is, in fact, quite difficult to generate good questions, and it might be worthwhile for the reader to set this book aside for a time at this point and make a list of questions he or she considers to be important in the area of language–brain relationships.

The perspective of much work in modern neurolinguistics is very broad, and can be thought of as "biological" in the fullest sense of the word. Neurolinguistics is concerned with how the brain represents and utilizes language, how this process develops throughout human life, how it is affected by disease, and whether and how it can be compared to analogous processes in non-human species.

Linguistic aphasiology is a recent, natural outgrowth of neurolinguistics. The study of language–brain relationships has traditionally utilized the technique of establishing "clinical–pathological correlations" as the database for theory construction. We shall consider this form of analysis in Chapter 2, and shall encounter many examples of such analyses in the text proper. For our present purpose, we need only note that this form of analysis characterizes the functional abilities of a patient as a deficit in normal functioning (the "clinical" side of the correlation) and describes the neural lesion (the "pathological" side). The part of the brain which has been damaged is then concluded to be normally responsible for the exercise of the function which is impaired. This form of analysis has led to more and more detailed analyses of linguistic and psycholinguistic deficits following brain injury. In recent years, the study of these deficits has become somewhat separated from the original concerns regarding the development of neurolinguistic theories, and has been more related to theories of normal language processing – a move from "neurolinguistics" to "linguistic aphasiology". Despite this drift, the fields are necessarily closely tied, and have many questions in common. The following are some of the basic concerns of many investigators in these areas.

1. *Reductionism*

A basic question in the philosophy of science in general is how various theories and sciences relate to each other. As applied to psychology, the question has special significance, because there are a number of researchers who have maintained that psychological and linguistic terms could be replaced by neurological and physiological terms, if only we knew enough about the latter. In fact, an important movement in American psychology, Behaviorism, adopted the philosophy that psychologists should restrict themselves to descriptions of observable behavior, and that references to internal mental states, such as what an organism knows or what its motivations are, are inappropriate in the science of psychology. Many behaviorists seemed to think that all such terms would ultimately be eliminated from theories of psychology by descriptions of neurological processes. In opposi-

tion to this belief, scientific study of language is now based upon the assumption that it is reasonable to speak of the internal mental life of humans (and of other species). The very first issue facing neurolinguistics is the philosophical one of whether this assumption is justifiable, or whether "neurolinguistics" will necessarily ultimately be reduced to purely neural science.

There is a second aspect to the question of whether psychological and linguistic terms are autonomous or simply a form of shorthand for descriptions of neurological events. This approach is based on the doctrine of the unity of science. Even if we do not believe that all terms referring to the mental life of humans will ultimately be understood in neurological terms, and do not accept the methodological restrictions of the behaviorists, we must still be sensitive to the claim that linguistics and the other psychological sciences must somehow be related to physical entities. If not, we are adopting a position such as dualism, which holds that there are various forms of biological "entities", some of which obey physical laws and some of which, such as mental and emotional entities, do not. It is a very general tenet of science that one should not postulate more distinctions than are absolutely necessary, and the idea that mental life is somehow radically different from physical life, and not related to physical structures and events at all, certainly postulates a radical distinction between various parts of biology, which would be best avoided if possible. Thus, the unity of science requires that we somehow relate linguistic and psychological terms to physiological terms.

The third reason for wanting to relate neurological and linguistic and psychological terms is that we have evidence that the brain is critically involved in language. A dualist would be in a difficult position to explain the effects of disease of the brain upon language and the many correlations between events in the brain and aspects of language which shall be presented in this book. He could, of course, claim that all these correlations are purely accidental, but most of us would find this claim unconvincing.

Thus, there are methodological, philosophical, and empirical reasons for believing that the brain must be related to language in some way. But what way? Is the strongest view, that the science of linguistics and the psychology of language are some day to be totally eliminated in favor of a rich science of neurology, tenable?

We do not in fact know how this question will ultimately be answered. What we can say is that the strongest view, total reduction of linguistics and psychology to neural science, is not the only one that is compatible with empirical observations of language–brain correlations, or with the requirements of philosophy of science. Fodor (1975) has outlined two general ways

in which psychological terms can be related to neurological terms. In the first, which he terms "type reductionism", the terms and laws of psychology are related to elements and laws of the brain in a principled way. In this case, a psychological law is true, or a psychological state exists, because it corresponds to some lawful event or events in the nervous system. Obviously, this approach postulates a complete reduction of psychology to neurology; in this system, psychological terms are merely shorthand expressions for neural states. However, there is an alternative to this view, which Fodor suggests – his "token physicalism". In token physicalism, every psychological state in fact is correlated with a neural state or structure, but the neural states and structures are not related to each other in any lawful way, except by virtue of whatever organization is imposed by the laws of linguistic and psychological science.

Two examples will make this position clear, both borrowed from Fodor (1975). Suppose we wish to relate economic theory to exchanges of items of value, such as currency or commodities. Clearly, there is a very large, possibly an infinite, number of methods of exchanging items of value: exchange of money, securities, land, items of trade, cattle, and so on. The laws of economics apply to exchanges in general, and are not reducible to descriptions of actual exchange. Laws such as "the law of diminishing returns" apply no matter what the medium of exchange. Thus, it can be true both that all laws of economics are in fact instantiated in some form of monetary exchange, and that they are not reducible to the laws governing actual monetary exchanges. The reason that they are not reducible is that the actual exchanges themselves consist of a large variety of activities, and no set of physical laws pertains to the purely financial aspects of all the actual instances of exchange. Only economic theory provides a lawful description of the financial aspects of exchange, and this theory cannot be replaced by a more detailed account of the exchanges themselves.

A second example is more directly pertinent. Most readers of this book will be somewhat familiar with the operations of modern computers. In these machines, various calculations are performed by the "hardware" of the central processing units of general-purpose computers. These calculations are transacted in particular computer languages via programs called "software". It is, in fact, the case that every software operation is accomplished by some part of a computer's hardware. On the other hand, it is also the case that the operations of the hardware are not organized in such a way that they can only accomplish certain software operations. Software obeys mathematical laws devised by humans. The hardware is *temporarily* organized by the particular calculation demanded by a particular program. The same hardware can be used with very different patterns of organization

in any two programs or any two programming languages. Thus, although the software is instantiated in the hardware, it cannot be described by the laws of the hardware.

This situation might be analogous to the way language and other psychological entities are related to the brain. It might be that the brain provides a "hardware" for the operation of various "computational softwares", and that the software temporarily organizes the neural "hardware" in particular ways which are specific to each set of software operations. If this were the case, all linguistic and other psychological structures and operations would be related to neurological events, but the laws and regularities regulating the operation of neurological terms with respect to linguistic and psychological events would be given by linguistics and psychology, not by physics and neurophysiology. The physical laws which govern the operation of the hardware would not totally constrain linguistic and psychological events, or determine linguistic or psychological laws. Under these conditions, it might be possible to replace linguistic and psychological terms by neural terms, but it would be uninformative to do so. There would be laws of linguistics and psychology which superimpose additional organizational structures upon the physical laws that apply to the physiological operation of the brain.

We can look at this question in one other way, which may help us to understand better the issues involved. The term "natural kind" refers to motivated divisions within a science. For instance, natural kinds in neurology include the concepts of "neurons", "convolutions", "synapses", "neurotransmitters", and others; in linguistics, items such as "noun phrase", "sentence", "referent", and "phoneme", as well as larger divisions of grammar such as "syntax", are all natural kinds. A slight but important rephrasing of the question of reductionism is to ask whether the natural kinds of linguistics and psycholinguistics are related to the natural kinds of neurology. There have been many suggestions of this sort, from the notion that all of language is the function of one hemisphere of the brain, to more specific and detailed hypotheses regarding correlates between aspects of language and language processing and areas and activity of the brain. If every natural kind of linguistics and psycholinguistics were related in a one-to-one fashion to a natural kind in neurology, it would be reasonable to say that linguistics is reducible to neurology. If this is not the case, then the relationship is along the lines of token physicalism described above. The first step in investigating whether this is the case is to see to what extent elements of language are correlated with particular parts and functions of the brain.

In our present state of knowledge, it is impossible to say which of these two types of relationship between language and the brain is true. The study

of language–brain relationships can be partly seen as an effort to distinguish these two possibilities, by providing a detailed theory of linguistic and neural structures and of their relationship. The point for the moment is simply that it is quite possible that the sciences which constitute the psychology of language may not be completely eliminable from a perfect science in favor of descriptions of neurological structures.

2. *Phylogenetic considerations*

What is it that enables man to master a language system for the representation of concepts and the communication of ideas, which is so useful in our adaptation to the world, and what is it that animals are missing that prevents them from developing the same system or similar systems? Putting the question this way assumes that animals have no system for the representation and communication of thoughts which is comparable to human language. Though this is a point which is the subject of debate, it seems to be the case that, although animals are capable of very intelligent behavior, they do not possess representational and communicative systems comparable to language. If we accept this assessment of non-human language abilities, and if we further accept the evidence that language is related to the functioning of the brain, we may conclude that the absence of language in other species is related to something about their brains.

It is, however, not obvious what humans have in the way of neural endowment that allows for language, and why animals do not have systems such as language. It is true that, in some respects at least, the human brain is larger than brains found in the majority of species, and that particular areas of the human brain are especially large and anatomically advanced. But some species have equally large brains which also have advanced structures, but do not appear to have similar systems. What makes the question especially difficult is the fact that many animals are capable of behaviors which require very complex calculations and plans. For instance, even so mundane an activity as a frog's snapping at one of two flies in its strike range, and not at the space in between them, requires extremely complicated mathematical considerations to describe. These descriptions of the frog's behavior can be seen as theories of the calculations accomplished by the frog's nervous system in this activity (Didday 1976). If frogs are capable of behavior which is the result of complex mathematical computations carried out by their nervous system, why do they not carry out the complex mathematical operations which are the basis for language or a similar system? Put slightly differently, considering how useful it is to have a system

of representation and communication of thoughts such as language, why has it not evolved in species which apparently are capable of complex operations in other areas?

One possibility is that, though other species are capable of complex cognitive tasks, language processing is still more complex. The alternative is that language, though not more complex, is special in some way, and different from other cognitive capacities. In either case, the ability to use a system like a human language must require special elements in the nervous system, or a special organization of elements of the nervous system, which are not present in animals. Note that these special features need not totally determine language functions, only support them, and thus this argument does not resolve the question of reductionism. Finding out what these elements are requires a detailed study of comparative neuroanatomy, as well as a detailed study of what functions are performed by various species, including the linguistic functions of humans. In other words, to answer the question we must have an understanding of just how language function actually differs from intellectual and complex behavioral functions of other animals, and how the parts of the nervous system responsible for language in humans and for these other behaviors in animals differ.

We may also make some progress in this area by analyzing other intellectual and psychological abilities of humans. Aside from our abilities with language, we have remarkable talents in a variety of other intellectual spheres, such as mathematics, logic, music, perception, and planning and co-ordination of action. Each of these areas differs in one way or another from language, either in terms of the organization of the intellectual or perceptual/motor system in question or in terms of the relationship between each system and items in the external world. If we compare language and music, for instance, we find that music obeys a set of internal laws, and can be used to evoke certain emotional states and memories; language also obeys a set of internal laws, and can be used to evoke emotional and intellectual states. The two systems differ significantly, though both are, for all practical purposes, unique to humans. Studying the similarities and differences in the way these systems relate to the human brain can give us information about the particular basis for language within the human brain.

3. *Developmental aspects*

Another general area of neurolinguistics is developmental (or "ontogenetic"). We are not born speaking language, and we are not born with a mature nervous system. In what way do the development of the nervous system and the development of our language abilities relate to each other?

One's first thought may very well be that the development of the brain has very little to do with the development of language, since brains presumably develop in similar ways in all language groups, but children learn the language that they are exposed to. If the child of English-speaking parents is taken to Japan, that child will learn Japanese, although his brain develops with no apparent difference from the ways it would develop if he were taken to France, where he would learn French, or if he remained in an English-speaking environment and learned English. Thus, to a very great extent, the development of language abilities seems to be determined by aspects of the environment, and has little to do with the developing brain.

But this view is quite superficial. Studies of the stages of language development show that children go through similar stages in the acquisition of languages, no matter what the particular structures of the language. Normal children go through a stage of babbling, followed by one in which they develop the particular set of sounds of the language they are learning, and they do the latter in predictable ways which can be stated for all languages. They then go through various other stages in the acquisition of vocabulary, syntax, intonation, and other structural elements of language. Moreover, as contemporary linguists have stressed, they acquire the language of the environment on the basis of incomplete and disorganized data, and they achieve a representation of that language that goes far beyond recall of the samples they have heard. It is this knowledge which enables them to understand and produce utterances they have never heard before. Thus, they show an ability to abstract an underlying system of knowledge of their language from the particular samples of language to which they are exposed, and to apply this knowledge in new and varied ways. All these observations point to an important contribution of internal biological factors to the acquisition of language.

Modern linguists have suggested that the acquisition of language is therefore determined by internal, innate, biologically determined abilities in conjunction with exposure to the language of the environment. One possibility is that the child has an innate system for recognizing, categorizing, and integrating linguistic information to which he is exposed, and that this system includes a framework of initial knowledge regarding the possible forms of language. Exposure to a particular language specifies particular aspects of the developing system, and constrains it within this innate framework (Chomsky 1981). The universal properties of languages are "known" by the child, because of his biological endowment, and specific features of the language he hears add to this innate knowledge to achieve a complete linguistic system.

This view suggests that the neurological correlates of language and

language development are of two different sorts. The first category of correlates would include those neurological structures which are related to universal aspects of language – related, that is, to those aspects of language structure which are innate, and which develop in the child due to intrinsic neural maturation. The second are those neural structures which are the result of exposure to a particular language. For instance, it might be the case that the knowledge that languages make use of systems of sounds, and that the systems of sounds are themselves structured in particular ways (such as that they consist of consonants and vowels, or openings and closings of the vocal tract), is innate universal knowledge, whereas the particular sounds of a language or a dialect are acquired on the basis of exposure. Since the universal aspects of language are, by definition, present in all languages, it is possible that they reflect universally present aspects of the human nervous system. The features of individual languages are also, clearly, related to the nervous system, but they vary from language to language, dialect to dialect, and even person to person. One consequence, therefore, of taking language development into account in neurolinguistics is that we must consider the possibility that different types of neurological structures may be related to these different aspects of language.

One way to consider this issue is for neurolinguistics to face the important and difficult question of characterizing the stages whereby both language and the brain develop. Although modern linguists have used the term "innate" to refer to the knowledge of language that humans have by virtue of their biological endowment, it is clear that this knowledge develops over time. By studying the sequence of maturational events in the nervous system, and of the language abilities of the child, we can hope to correlate neural structures and language functions, thus providing another important approach to the understanding of the relationship between language and the mature adult brain. This is not sufficient, however. We must also distinguish universal and language-specific aspects of development, and correlate each with neural structures. Since universal features of language are embedded in language-specific development, this task requires careful cross-linguistic experimentation with normal children and observation of children with abnormal language development to separate these features.

4. *Language pathology*

The final set of questions that are central to neurolinguistics are also those which constitute the subject matter of linguistic aphasiology: the study of acquired disorders of language. Aphasias – disorders of language that are caused by diseases of the brain – have been investigated scientifically for

over a century. This study is a topic in its own right, and constitutes the central body of fact and theory upon which neurolinguistics is presently based.

One basic question which occurs frequently in the study of language pathology is whether language breakdown is related in natural ways to the structure of normal language. Do individual patients and groups of patients have disorders of language which are confined to particular types of language structures or processes? For instance, do certain patients or groups of patients only have trouble speaking and no difficulty understanding speech, or do they have a disorder affecting only syntactic structures and not the sound pattern of their language?

Our first reaction to questions like these must be skepticism that such patterns will be found. After all, injuries to the brain such as stroke, trauma, and tumor do not leave neat areas of destruction ("lesions") in particular locations in the brain. Stroke follows patterns of vessels, trauma depends on its cause, and tumors grow locally and spread via the blood-stream. None of these diseases causes lesions which we would expect to be related to particular aspects of language. Furthermore, even if lesions were relatively "neat", specific breakdown patterns would only arise following brain injury if particular aspects of language processing were the responsibility of individual areas of the brain, and this might well not be the case. At the very least, it would be hard to recognize such patterns, since language itself is organized in complex interactive ways, and a disorder of one aspect of linguistic structure might be due to a patient's inability to deal with a quite different aspect of language (we shall review an analysis of this sort in Chapter 15). It is therefore interesting and important that, despite these considerations, many specific patterns of language breakdown have been described. These isolated deficits bear on theories of normal language structures and processing. To the extent to which they are related to types and locations of neurological pathology, these isolated disturbances are the basis for inferences from pathological language to the relationship between normal language and the brain.

Another question which has often been raised regarding language disorders is whether they parallel language development in reverse. This question is related to another aspect of linguistic aphasiology: the regularity of language breakdown (as opposed to the specificity of isolated deficits). Some aspects of language and language processing are retained after others have been disturbed by injury. When the retained and disturbed processes and structures are within the same domain, rather than in different areas – as, for instance, when a patient cannot read long words but can read short ones – these patterns may be related to the complexity of processing of the

different structures. In some cases, elements which are retained after brain injury are also those which develop first in childhood, and those which are lost are those which are last to develop. In these cases, the comparison of aphasic abilities and developmental sequences can provide powerful evidence for the relative complexity of one structure or process compared with another within a single area of language function. This is not always true, however; and the study of the areas in which it is and is not true is an important method of determining the relative complexity and interdependence of linguistic forms.

The question of orderly breakdown of language within a given domain is related to a third neurolinguistic question: whether the brain can support language in many different ways or whether it can do so only in one or in a limited number of forms. If language breakdown is always orderly within each sub-domain of language, no matter what the neural insult causing aphasia, we can conclude that, no matter how the brain is injured and how it reorganizes after injury, those neural elements and organizational features which support language do so in highly restricted ways. Of course, it is another matter to discover what neural elements and organizational features are responsible for language; but the existence of regular patterns of breakdown – if they exist – would indicate that the ways in which neural tissue supports language are restricted, even when neural tissue is incomplete, damaged, and partially self-repaired.

Finally, the study of linguistic aphasiology is of interest as a branch of abnormal human cognitive psychology. Whatever the relationship of specific domains of breakdown to components of normal language, and regardless of the possible ordered nature of language impairment within a domain, linguistic aphasiology deals with a field of abnormal psychology which is worth describing in and of itself, and which may be worth understanding in detail for the practical purpose of guiding rehabilitation efforts.

We have touched upon four general areas in which questions have been raised about the relationship between language and the brain. There are many other questions that can be asked about these matters, but these four are central to the fields of neurolinguistics and linguistic aphasiology, and provide a good place to start. Before turning to the ways in which these questions may be studied, it is worth noting two important points regarding all these areas of inquiry.

First, we can summarize many of the questions by saying that the goal of neurolinguistics is to characterize the relationship between elements and operations in the theory of language and language processing and elements and functions in the theory of neural tissue. If we could establish that