Language and the Brain

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CAMBRIDGE UNIVERSITY PRESS
1 Neurolinguistics

"Little words, no" is how one brain-damaged patient described his loss of language. Another whose comprehension of spoken and written languages was markedly worse than that of the first patient, reported "The small words are too big for me." We see from the form of their utterances as well as their content that these two patients are suffering from different types of language breakdown.

What can their problems tell us about how the human brain permits us to speak and understand what others say? Study of such aphasic individuals - people whose brain damage has affected some or all of their language skills - has been at the core of neurolinguistics.

What is neurolinguistics?

Neurolinguistics, as its name implies, is the study of how the brain ("neuro") permits us to have language ("linguistics"). Neurologists study brain and nerve systems; those neurologists who contribute to the field of neurolinguistics study human neurology and how behavior breaks down after damage to the brain and nervous system. They might ask about the two patients mentioned above where precisely their brain damage lies. Linguists study the way human language is structured. Those linguists who contribute to the field of neurolinguistics are interested in how language structures can be instantiated in the brain. They would observe that the first patient quoted above actually avoided using many of the "small words" one might have expected, yet included one ("no"), and ask why this is.
The structure of this book

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for language. As we mentioned in the preface, it is these groups that we have used to structure most of the rest of the book, so readers can see what sorts of information have been and can be gleaned from studies of each of them.

Aphasics -- individuals like those cited at the beginning of this chapter who have suffered brain damage with the result that aspects of their language are impaired -- were the first population to permit study of the systematic breakdown of language. From that breakdown we learn what the components of language are as they must be represented in the brain and processed by it. Because so much work has been done on aphasics' language, we have written two chapters on aphasia for this book, one focusing on the symptoms and syndromes as our interpretation of these has developed, and the second on the more modern linguistic understandings that derive from studying the phenomena of aphasia and attempting to elucidate theories to explain them. In these chapters we discuss types of questions that working with aphasics leads us to, questions like:

- If some aspects of language are impaired and others are not, what does that tell us about the way language is organized in the normal brain?
- If we see certain patterns of recovery from aphasia, what does that tell us about how the brain is organized for learning language and processing it?

Following the studies of aphasia in adults, we discuss childhood aphasia. In some ways, the sudden onset of language problems in childhood, due to brain damage, is similar to that of adulthood, but in other interesting ways it is different because both the brain and language of the child are still maturing, while those of the adult are more mature and stable. A study of such children permits us to discuss the notion of plasticity, that is, the way the brain can reorganize itself after damage, at least during childhood. Linked to "plasticity" is the notion of a critical period for language acquisition, that is a period, somewhere in childhood or at puberty, after which learning language becomes markedly more difficult. This difficulty arises, presumably, because of loss of the brain templates that we assume children are born with that permit them to learn language. Also lost over time is the possibility of creating many new connections among brain cells that make language acquisition easy in young children. We also consider the case of Genie, a modern-day "wild child," to learn what severe deprivation of language throughout childhood teaches us about brain organization for language and the critical period. In this chapter (Chapter 6) we discuss people with language disorders that run in families because their performance on language tasks gives us hints about the ways the normal newborn's brain must be ordered for language processing to occur.

Aphasia in adults is virtually always the result of disturbances to what we call the "language area" of the brain, that is, the part of the brain that is crucial for many aspects of language; see Figure 1.1. The language area is relatively circumscribed in what we call the dominant, left hemisphere (dominant because for most humans language seems to rely more heavily on it). However, disturbances in language performance more broadly construed can be seen in patients with brain damage outside this language area. Most interesting of this group are patients whose brain damage is not to the so-called language "dominant" hemisphere but to the so-called "non-dominant" one, usually the right hemisphere. Thus we devote a chapter (Chapter 7) to discussion of what we learn about language organization in the brain from study of this population whose core linguistic abilities (phonology, syntax, and, often, lexical access) appear quite spared, yet whose discourse and other pragmatic aspects of language are somewhat deviant. From right-brain-damaged patients we can ask how aspects of language other than the ones that linguists have traditionally thought of as core aspects can systematically break down with brain damage. From such studies we learn about the participation of the non-dominant hemisphere in pragmatic aspects of language performance among normals.

WerLucie -- the next neurologist after Broca who moved our field forward -- tossed with the relationship between language and thought in his classic 1874 paper where he described two fluent aphasics, one of whom, we maintain (Mathews, Oller, and Albert, 1994) was clearly demented. Alzheimer himself, the neurologist after whom the most common dementing disease in the Western
The two main processes involved in the brain's understanding of vision and language are the visual and auditory systems. These systems are strongly interconnected and work together to process information from the environment. The visual system processes information from the eyes, analyzing shapes, colors, and movements. The auditory system processes sound, allowing us to understand speech and other auditory stimuli. Both systems are essential for language comprehension and production, with the brain's neural networks adapting and changing in response to experience.
Language and the brain...

Two major schools in the study of neurophilosophy are neuroscience and communication. These are discussed in the next section.

Neurophilosophy...

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Neuroscientists

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Figure 1.1. Lateralization: Unilateral centrencephalic model of language. (Adapted from Spaarn, 1987: 27.)

The brain's left hemisphere specializes in language and logic, while the right hemisphere is more involved in spatial reasoning and pattern recognition.

The model proposes that different areas of the brain are responsible for different functions, which can be seen on a computer screen. Different areas of the brain appear to light up when a healthy person is understanding certain information.
The brain and spinal cord, and the peripheral nervous system. The peripheral nervous system consists of the central nervous system (the brain and spinal cord) and the peripheral nervous system (the nerves). This complex network of nerves and neurons is essential for the proper functioning of the body. The human nervous system has two main parts: the central nervous system, which includes the brain and the spinal cord, and the peripheral nervous system, which consists of all the nerves in the body.

The brain is the control center of the nervous system. It processes information from the sensory organs, such as the eyes and ears, and sends signals to the muscles and glands throughout the body. The brain is divided into several parts, each with a specific function. For example, the cerebrum is responsible for higher brain functions such as thinking and decision-making, while the cerebellum is responsible for coordination and movement.

The spinal cord is a long, tubular structure that runs from the brain down the center of the back. It is made up of many nerve fibers that carry messages from the brain to the muscles and organs throughout the body. The spinal cord is also involved in the control of reflex actions, such as the ability to blink when an object is close enough to the eye to cause discomfort.

The peripheral nervous system consists of all the nerves that connect the central nervous system to the rest of the body. These nerves carry signals to and from the brain and spinal cord, allowing the body to communicate with the rest of the world. The peripheral nervous system is divided into two parts: the somatic nervous system, which controls the voluntary muscles, and the autonomic nervous system, which controls the involuntary muscles and glands.

Although the field of neuroscience is relatively young, it has already made significant advances in our understanding of the brain and nervous system. Future research will continue to shed light on the many mysteries of the brain and how it works. However, it is important to remember that our knowledge is constantly evolving and that new discoveries are being made every day.
regulates body functions such as breathing and temperature maintenance. This system is called the autonomic nervous system. Its functions are carried out more or less without our conscious awareness. Although breathing must be coordinated with speech, an understanding of the autonomic nervous system is not necessary for an appreciation of the research described in this book and we will not return to it.

We are, however, concerned with other aspects of the peripheral nervous system. In order to speak, the muscles that control articulators such as the tongue and jaw must be contracted in just the right sequence. If a message is to be written, the muscles in the hand must be properly controlled. For the creation of signs in a visual-gestural language (commonly called a sign language), overall body posture, facial expression and hand movements must all be coordinated. Each of the muscles necessary for communication is controlled by nerves that are connected ultimately to areas in the brain. It will be our goal in this chapter to present information on the components of the central nervous system – and particularly those that contribute to language – and to describe generally its connection to the peripheral nervous system.

**Nerves**

Each nerve or neuron consists of a cell body and one or more extensions that are similar in function to the electric cords that connect power sources to appliances. These extensions can be extremely long and may carry impulses toward or away from the cell body. The axon of a cell is the extension which carries impulses away from the cell body. Extensions which carry impulses toward the cell body are called dendrites. For example, a motor neuron located in the spinal cord may have an axon which extends all of the way through the legs and ends in the muscle fibers of the toes. A schematic drawing of a generic motor neuron is seen in Figure 2.1. The reader is left to imagine the possibility of an axon extending several feet rather than inches.

One single axon may control the movement of a number of muscle fibers. The nerve cell body, its axon and the muscle fibers it controls are called a motor unit. Different muscles have different numbers of muscle fibers. The number of muscle fibers controlled by a nerve cell is also not the same for all muscles. A particular muscle may have a number of muscle fibers per motor unit ranging from under 100 to 2,000. If a muscle, such as the muscle of the thigh, has a very large number of muscle fibers per motor unit, that muscle, being controlled by only a small number of nerves, will not be capable of delicate movements. If, on the other hand, many nerves control the movement of separate muscle fibers in a muscle, as in the mouth, a more precise degree of control can be exercised.

A motor neuron exercises control of the muscle fibers in its motor unit by causing the electrochemical changes necessary to
force the contraction of the muscle. This is possible because each muscle fiber in the unit has the motor ending from a peripheral nerve (see Figure 2.2). When a nerve impulse reaches these motor endings, a substance called acetylcholine is released. This substance combines with a receptor substance and makes the changes necessary to the muscle cell membranes in order to cause contraction of the muscle.

The simplified description above brings the reader only from the spinal cord to the skeletal muscle. We must also understand the origination of nerve impulses in the brain as well as pathways that lead from sensory receptors to the brain. It is also important to realize that while flexing one’s toes is fairly readily understood using the above description, much more subtle issues of timing arise when considering complex movements such as talking. For example, the tongue is controlled by a cranial nerve pair called the hypoglossal nerves. Each hypoglossal nerve goes to one half of the tongue. Complex messages from the brain must be sent in order to control the tongue properly for speech. For example, the difference between the [t] and [k] sounds in English cannot be described in terms of simple contraction or relaxation of “the tongue.” The entire shape of the tongue is different for these two sounds. For [t], the tip of the tongue touches the front part of the roof of the mouth. For [k] it is the back of the tongue that touches the back of the roof of the mouth. This will become particularly important in our discussion of speech planning and speech errors in the chapters on aphasia, chapters 4 and 5.

The central nervous system

The spinal cord itself— that bundle of nerves connecting the brain and peripheral body parts—is housed within the spinal column. The spinal column is a series of individual bones or vertebrae each of which has a hollow center and openings at the sides. The bones are joined together by cartilage to form a column which begins at the base of the skull, extends the length of the back, and ends in the coccyx or “tail-bone.” Its purpose is to support the body, allow movement of the torso and protect the spinal cord, which, along with protective fluids, fills the hollow

[Figure 2.2 A schematic of motor neurons controlling muscle fibers. (Adapted from Gardner, 1968: 147.)]

centers of the column. The side openings in the vertebrae allow for pairs of spinal nerves to go out from and into the spinal cord.

The spinal cord actually continues up into the skull where it is joined with the brain stem, sometimes called the “primitive brain” because it is involved with maintaining unconscious functions such as consciousness and breathing. Wedged between the brain stem and the back of the cerebrum (discussed below) is the cerebellum. The cerebellum is comprised of two hemispheres joined by a middle piece. It is an important structure for the control of muscles.

The brain hemispheres

Although a cursory knowledge of all of the structures of the central nervous system provides context for a full understanding of research concerning brain representation for language, the largest portion of the human brain, and by far the most important for
issues in speech and language is the cerebrum. Some basic facts about the cerebrum are obvious from an initial observation. (See Figure 2.3.) The cerebrum, like the cerebellum, is divided into two hemispheres, right and left. The cerebral hemispheres are not entirely separate; they are connected by fiber bundles, the most important of which is the corpus callosum. The surface of the cerebral hemispheres is the cortex which is distinguished by its convolutions; the hills and valleys known as gyri and sulci respectively. These can be seen in Figures 2.3 and 2.4.

A closer look at each hemisphere shows that certain of the gyri and sulci are particularly pronounced and can be used to delimit four lobes: the temporal, occipital, parietal and frontal lobes. The important sulci, gyri, and lobes are marked in Figure 2.4. The Rolando fissure separates the frontal and parietal lobes: the Sylvian fissure cuts through the language area, with the temporal lobe below and the parietal and frontal lobes above. The frontal lobe is often referred to as an anterior region of the brain; the parietal lobe is posterior to it, as is the occipital lobe. As the temporal lobe runs from front to back, it has both anterior and posterior sections.

Another approach to delimiting regions within the cerebral hemispheres is to study the types of cells to be found in each region, as a neuropathologist, Korbinian Brodmann, did last century. The subtle differences in density of cell type are represented schematically in Figure 2.5. The upper picture represents the visible surface of a hemisphere. The lower picture represents the part that faces the other hemisphere.

The outer surface or cortex of both cerebral hemispheres is grayish in appearance if the brain is dissected and stained after death. This outer layer consists mostly of nerve cell bodies and is referred to as "gray matter." Beneath the gray matter are the sub-cortical regions or "white matter" which consists for the most part of nerve cell fibers. There are, however, additional areas of "gray matter" on the insides of the cerebral hemispheres. Figure 2.6 shows a slice of the brain prepared with a stain which colors only gray matter.

Although the cortex is most crucial for language, subcortical areas also participate. Most of the subcortical areas are seen as white matter when staining techniques are used. Some specific

Figure 2.3 Looking down on the two cortical hemispheres. (Adapted from Sidman and Sidman, 1965: 193.)

Figure 2.4 Important lobes, fissures, and gyri of the cortex.
structures in the center of the brain are gray matter, however, such as the thalamus and hypothalamus. These structures are primarily involved with more basic functions than language (e.g. sleep, appetite, sexual desire). However, one ridge of white matter among them, the internal capsule, is implicated in aphasia. Also the temporal isthmus along with the arcuate fasciculus connects anterior and posterior cortical areas involved in language.

**Individual differences in development of the brain**

The many structures described above all originate from the neural plate, a single layer of cells which develops in the middle of the back of human embryos early in gestation. This single layer begins to differentiate into three layers of distinct cell types. The amazing neuroanatomical complexity of the brain is realized.
through a continued differentiation of cell types and migration of cells to distinct locations in the developing brain. Each stage is dependent on both genetic messages and fetal hormonal environment.

It has been suggested (Geschwind & Behan, 1982, Geschwind & Galaburda, 1985) that the presence of some unusual traits in individuals and individual families may be attributed to an unusual fetal hormonal environment. A certain balance of hormones helps trigger normal fetal development. In these individuals, they posit, unusual amounts of certain hormones – especially testosterone – at crucial stages around the third and fourth months of fetal development – trigger unusual patterns of brain development. The basic tenets of the “Geschwind/Galaburda Hypothesis” can be summarized as follows:

During the third and fourth months of fetal growth, three systems are developing: the system for lateral dominance whereby one hemisphere of the brain will be responsible for handedness and language, the endocrinological system, and the immune system. Unusual hormonal events, that tend to run in families, they hypothesize, may lead to cells migrating in unusual patterns. This may result in underdevelopment in certain areas (say those necessary for reading in the dyslexic child who will have difficulty learning to read) and overdevelopment of other areas – either contiguous ones in the same hemisphere, or analogous ones in the other hemisphere. This overdevelopment may be responsible for special talents (such as music or math) as well as disabilities. Whatever causes this unusual hemispheric development appears to result in unusual immune system phenomena (e.g. a proneness to allergies) as well as unusual endocrinological phenomena (e.g. twinning and, in their analysis, homosexuality).

The possibility of subtle individual differences in brain organization adds another dimension of complexity to the study of brain representation for language. We will return to these issues in the sections in later chapters on language performance in left-handers and talented second language acquisition.

Cortical brain regions important for language

In this section we must consider the lobes and subsections in greater detail than we did earlier in this chapter. Although both afferent (toward the brain) and efferent (away from the brain) fibers are present in most parts of the cerebral cortex, some regions have a particularly high concentration of fibers of one or another type. For example, there is an area (Brodmann's area 4, see Figure 2.5) that lies at the back of the frontal lobe just in front of the Rolandic fissure, that contains mostly fibers that lead to motor neurons, those responsible for generating movement. By electrically stimulating the cells in this area, it has been possible to “map out” the motor cortex, that is to determine where nerve impulses that control the musculature in various areas must originate. An example of such a generally agreed upon map of the motor cortex is found below (see Figure 2.7).

This primary motor area, or motor strip, exists in both hemispheres of the cerebral cortex. Stimulating a cortical area in one hemisphere usually makes the muscles on the opposite side of the body move. This is because most of the nerve fibers cross over to the opposite or contralateral side. There is some representation in each cerebral hemisphere for the ipsilateral or same-side muscles but the strongest connections are those that run to the opposite side.

Similarly, it has been possible to determine which cortical areas contain nerve fibers that receive sensory input, the somatosensory areas. The various areas of the body send sensory information to a cortical area in the contralateral hemisphere area just across the Rolandic fissure from the motor strip. This primary somatosensory area is in the front of the parietal lobe.

The primary area for the reception of visual stimuli is in the occipital lobe. The representation of visual information is somewhat more complex than the brain representation for muscles. In the motor cortex, it is possible to say more or less accurately that the motor cortex of the left hemisphere controls movement of the right side of the body. Most of the visual pathways are also contralateral. However, rather than information from the right eye coming to the left hemisphere, information from the right visual field comes to the left hemisphere. The visual field is the area which can be seen without movement of the head or eyes. The midpoint in that field is the dividing line between the left and right visual fields. Both eyes see both fields. Both the left and right eye send information about the left visual field to the right hemisphere and
information about the right visual field to the left hemisphere (see Figure 2.8). Of course, information can be shared between the two hemispheres because they are connected by the corpus callosum (see Figure 2.8).

The temporal lobe contains Heschl's gyrus, a structure particularly important for the reception of auditory stimuli. Again, there are both contralateral and ipsilateral pathways between the ears and the cerebral hemispheres, but the contralateral pathways are the predominant ones.

Figure 2.7 Motor and sensory cortex. (Adapted from Donner, “Brain function and blood flow,” in Scientific American, 1978: 64 and 68.)

Figure 2.8 Visual pathways. (Adapted from Schneider and Tarshish, An Introduction to Physiological Psychology, McGraw Hill, 3rd edn, 1986: 645.)

If one pulls the temporal lobe away from the parietal lobe, over Heschl’s gyrus and extending to the juncture between the temporal and parietal lobes lies the planum temporale. Because this area of cortex is markedly larger in the left hemisphere of most humans than in the right, and because it is contiguous to the other language areas, it is considered important for language (see Figure 2.4) as a secondary association area.

Indeed, contiguous to each of the primary areas (namely the motor strip for outgoing speech and Heschl's gyrus for perceiving speech) are secondary association areas where a higher level of processing takes place. Behind Heschl's gyrus is Wernicke’s area (discussed in chapter 4) which appears to be necessary for making sense out of the auditory stimuli that come in and are judged by the primary auditory area to be speech, rather than non-language noises. In front of the primary motor area is Broca’s area (also discussed in chapter 4) which is involved in motor planning (and perhaps syntactic processing) specific for speech.
3 How we know what we know about brain organization for language

Left-hemisphere dominance for language

The search for localized brain centers for speech and language has a long and interesting history. The first group of neurologists to search for an area of the brain dedicated to language function were the phrenologists of the early nineteenth century to whom we referred earlier. Proponents of this school of thought believed that particular talents or personality traits manifested themselves in increased development in particular cortical areas with subsequent effects on the actual shape of the cranium or skull. Close examination of the skull, they believed, could lead to an understanding of the inner person. The phrenologists, such as Gall in England, Spurzheim in Germany and Bouillaud in France, believed the language faculty to be located in the two frontal lobes. In fact Bouillaud went so far as to offer a prize to anyone who could find a patient with linguistic deficits and no frontal lobe damage! There was some disagreement among phrenologists as to whether there was a single language faculty or perhaps, as Gall suggested, one center for the memory of words and another for articulate speech (Brown & Chobor, 1992).

Data from brain damage

As early as 1836, John Abercrombie, a prominent Scottish physician, published data from which the association of left-brain damage with linguistic deficits was clear. As Hans Forstl (1991)
points out in his review of Abercrombie's work, it was probably a
reaction to the rather fanciful drawing of conclusions in phrenol-
ogy that led Abercrombie to publish his observations without
drawing attention to the obvious conclusion of left-hemisphere
dominance for language.

More often cited as the first linking of the left hemisphere to
language is the 1836 paper of Marc Dax. "Lesions of the Left Half
of the Brain Associated with the Loss of Signs of Thought," which
represented the results of Dax's study on a large series of brain-
injured patients. Forstl (1991) attributes the fact that this signi-
ficant work was never published to the strength of the phrenologi-
cal camp.

In fact it is the neurologist/anthropologist Paul Broca who is
credited with discovering, and reporting in his 1865 paper, that
language loss after brain injury was far more common after left-
sided injury than after right-sided injury. More recent studies
suggest that approximately 97% of the population has language
represented predominantly in the left hemisphere. Of the remain-
ing 3%, most are left-handed. Since we estimate that some 10% of
the population is left-handed, this means that the majority of
left-handed individuals also have language represented in their left
hemisphere.

How do we know that 3% of the population has language
represented primarily in the right hemisphere? There are a certain
number of cases of "crossed aphasia"; that is right-handers with
language deficits after right-sided injury. It was evident even in the
series examined by Abercrombie in the 1800s that there was a
small percentage of people with right-hemisphere representation
for language.

Data from anesthetizing one hemisphere

In more recent times we have also been able to determine the
dominant hemisphere for language in uninjured brains. In a tech-
nique called the Wada test, an anesthetic called sodium amytal is
injected into the artery leading to one side of the brain or the
other. If the drug is delivered to the language side of the brain,
a temporary paralysis of language function is experienced. The

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patient stands with both arms extended forward from the should-
ers. Slowly the arm opposite the patient's "language" hemi-
sphere - usually the right arm - goes down as the brain areas of
that opposite hemisphere that should be available for keeping it up
are no longer operating. The patient cannot speak at all for several
minutes and in the minutes after that, language sounds aphasic,
somewhat like the first patient cited at the beginning of the first
chapter.

The results of this test confirm the statistics from incidence of
aphasia after brain injury. Among right-handers with no history of
early left-brain damage, approximately 95% experience temporary
interference with language after an injection of sodium amylate
into the left carotid artery, which brings blood to the left hemi-
sphere. Approximately 70% of left-handers experience similar in-
terference after left carotid injection. Of the remaining 30%, half
only have temporary paralysis of language function after right
carotid injection. The other half would seem to have at least some
degree of bilateral speech control (Hécaen & Albert, 1978). The
numbers for manual/visual languages may be a bit different. Some
signers exhibit aphasic symptoms after left hemisphere injection of
sodium-amytal (Damasia et al., 1986). However, there is some
research suggesting greater right hemisphere involvement in pro-
cessing sign language (see Poizner, Klima & Bellugi, 1987, for a
review). The Wada test is used primarily as a method of determi-
nating which hemisphere is dominant for language in patients who
must undergo brain surgery. The brains of these surgery patients,
frequently epileptics for whom medications have not worked to
control the epilepsy, while not acutely injured, by definition have
some neurological problem. In neurologically normal populations,
there would likely be even less indication of bilateral representa-
tion for speech/language.

Tachistoscopic presentation

It is also possible to present visual stimuli selectively to one
hemisphere or the other in normal individuals in order to learn
about which hemisphere is involved in processing them. When a
person looks at a point, everything to the right of that point is in
the right visual field. Everything to the left of that point is in the left visual field. Ordinarily, both eyes see both visual fields. However, information about the right visual field is sent by both eyes to the left hemisphere and information about the left visual field is sent by both eyes to the right hemisphere. Recall that Figure 2.8 illustrates the normal operation of visual perception.

The technique called tachistoscopic presentation allows normal subjects to react to a visual stimulus presented to only one visual field. The stimulus is flashed to one or the other side of the fixation point so briefly that the subjects do not have time to change their gaze, allowing the image to be part of the other visual field. In normal subjects the left and right visual areas of the brain communicate via the corpus callosum. This means that information will be processed regardless of the visual field in which it is presented. However, linguistic stimuli will be processed more quickly and more accurately when presented to the right visual field (left hemisphere). Such a pattern can be seen in tachistoscopic testing over a number of stimuli. While tachistoscopic presentation is not as accurate as brain damage in indicating which side of the brain is dominant for language (only between 60% and 70% of normals demonstrate a left-hemisphere dominance for language, for example, via tachistoscopic presentation, while from brain damage studies we know the numbers should be higher, closer to 97%), the technique is certainly non-invasive, and thus substantial numbers of tachistoscopic studies have been conducted since the 1950s to determine which hemisphere is dominant for different aspects of language and non-language processing.

The dichotic listening technique

A second technique that has been developed to study lateral dominance in normal individuals is called dichotic listening. While tachistoscopic presentation uses visual stimuli, dichotic presentation uses auditory stimuli. This technique relies on the fact that the right ear has stronger connections to the left hemisphere than it does to the right (and conversely for the left ear). Thus information presented to the right ear, while it will be sent to both hemispheres' auditory centers, will be better processed contralaterally. Under normal circumstances, we see no effects of this curious organization, but when we “overload the system,” we can infer that one hemisphere or the other performs better for a given sort of stimulus type. For example, if normal subjects hear triads of different words presented simultaneously to both ears (the right ear might hear “2,” “8,” “5” while the left ear hears “9,” “1,” “6”), and asked to repeat back everything they hear, most subjects are more likely to forget “1,” the information that went to the left ear—that is, the right hemisphere— from the mid-point of the triad. Over a number of trials, we can see a consistent performance for language materials like these numbers that is the opposite of the pattern we see for non-verbal meaningful materials such as babies' cries, fire sirens, bird whistles, etc. This technique, then, complements tachistoscopic presentation in allowing us to evaluate lateral dominance for spoken language as well as written language. As with tachistoscopic presentation, it does not give us the same clarity that explicit brain damage does, but it is infinitely easier to manipulate.

Split-brain patients

Under normal circumstances, the two halves of the brain work in tandem. Sensory information travels along pathways from one side of the body to the opposite side of the brain. Acoustic stimuli arrive at the brain along both contralateral and ipsilateral pathways. Visual information from each visual hemifield is sent to the opposite hemisphere (see Figure 2.8). In the normal human brain, all of this information is shared between the two hemispheres as signals are passed via the corpus callosum, the bundle of some 200 million nerve fibers connecting the left and right hemispheres. There is, however, a small but well-studied population of individuals in whom this inter-hemispheric communication is no longer possible. The same fibers which allow for the sharing of information between the two hemispheres unfortunately also allow for the electrical misstrings which result in a kind of intractable, epileptic seizure. In some cases the only way to allow the patient to live productively is to sever the main inter-hemispheric connections in a process called a commissurotomy. This procedure was developed
in the 1940s and 1950s but its use declined as better drugs were
developed for managing epilepsy. The everyday behavior of these
“split-brain” patients is essentially normal. Occasional eerie re-
ports of dissociation of behavior of the left and right sides of the
body are reported. Some patients report difficulty in learning new
name-face connections. The right hemisphere seems to be particu-
larly involved in interpreting visual-spatial information, in this
case, the appearance of the new face. The left hemisphere will
process the new linguistic information: the name. It is not surpris-
ing that this particular kind of learning would be problematic after
a commissurotomy. Beginning in the 1950s, many experiments
were performed testing the linguistic abilities of the isolated left
and right hemispheres in these patients.

One type of experiment has the split-brain patient sit at a table
with a screen blocking the view of objects on the other side. If the
patient reaches behind the screen with the left hand, tactile infor-
mation about the object is conveyed only to the right hemisphere
and the person will be unable to name the object held. Objects not
seen, but held in the right hand are readily named. The isolated
right hemisphere can process the tactile information. It can guide
the left hand to choose a similar item from an array of items, but it
cannot name the item. From such a study we can learn what
language the isolated right hemisphere can process and how indepen-
dent the isolated left hemisphere can be in processing
language (see chapter 7).

Localization of language within the left
hemisphere

The dominance of the left hemisphere for language for most
people is largely uncontroversial. Determining the particular left
hemisphere areas involved in the various aspects of language
comprehension and production is more difficult.

History

The claim that linguistic ability is localized in a particular area
of the left hemisphere is generally credited to the French neurol-
ologist Paul Broca. In 1861 (interestingly, four years before he
noted that left- but not right-sided brain damage seemed to result
in language disturbance) he presented data that implicated the
area of the frontal lobe just in front of the Sylvian fissure in
language function. In 1874, Carl Wernicke demonstrated that for
two patients he had seen, damage to an area in back of the
Sylvian fissure had caused linguistic deficits. The trends toward
describing very specific left-hemisphere areas and ascribing specific
language functions to these areas continued for some time.
Henderson et al. (1992) quote a prominent professor of medicine,
Ludwig Lichtheim, who wrote that once aphasiologists had deter-
mined the ways in which language functions were localized and
interconnected in the brain, neurologists “should then be able to
determine the exact place of any discontinuity in these paths and
account for its symptomatic manifestations with the same preci-
sion as we do for those of a motor or sensory paralysis depend-
ing on a lesion of the peripheral nerves” (Lichtheim, 1885).

As Henderson explains, not all neurologists of the late nine-
teenth century were comfortable with this narrow delimitation of
speech centers. Hughlings Jackson (1878) pointed out that “to
locate the damage which destroys speech and to locate speech are
two different things.” Freud (1891) agreed with Jackson’s skepti-
cism in interpreting aphasiological data. For Freud, it seemed
likely that there was only one type of aphasia. Different symptoms
such as those found in Broca’s vs. Wernicke’s patients (discussed
in the next two chapters) were to be explained by the proximity of
the patients’ lesions to either motor or sensory areas in the left
hemisphere.

Modern aphasiologists are still not entirely in agreement over
the extent to which specific language functions are subverted by
specific brain areas. The details of some of these debates will be the
material for the following chapters. However, even the “localiza-
tionists” of today have heeded the cautions of the past, as can be
seen from a comparison of Lichtheim’s schematic drawing of
brain representation for language (Figure 1.2) and a modern
schematic drawing of the language areas of the left hemisphere
(Figure 1.1).
Cortical stimulation

One modern technique that is useful in determining which areas of the left hemisphere are involved in language processing is called cortical stimulation. Consider the maps one can make of left-hemisphere sites where electrical stimulation interferes with naming ability in hearing individuals.

In order to determine which cortical areas of the brain are involved in speech production in patients who need to have brain tissue removed because of intractable epilepsy, electrical stimulation of the brain surface is used to make a map of the patient’s brain. The brain does not contain pain receptors so patients may remain conscious and attempt to name pictured items while electrical stimulation is being applied to different points in their brains (See Figure 3.1). If the stimulation is in an area of the brain normally involved in speech, it interferes with patients’ ability to name; they may be totally unable to speak or unable only to name a simple picture of an object. Alternately, they may experience hesitation, slurring or repetition in attempts at naming the pictured object. This interference never follows the stimulation of parts of the non-language-dominant half of the patient’s brain (Penfield & Roberts, 1959).

It is of interest to consider the effects of cortical stimulation on a signed language. Haglund et al., 1993, tested a woman who had learned American Sign Language (ASL) as a child. Left-hemisphere stimulation affected both languages but some areas affected primarily ASL and other areas affected primarily English.

Imaging techniques

Only recently have imaging techniques such as CAT-scans (Computerized Axial Tomography), PET-scans (Positron Emission Tomography) and MRIs (Magnetic Resonance Imaging) offered precise information about lesion sites in living patients.

In these techniques, people’s brains are “x-rayed” and computer programs convert the pictures into maps we can recognize. CT-scans are good at localizing many sorts of lesions, but not very recent ones or ones very close to the skull. MRI scans can demonstrate some of the lesions that CAT-scans cannot. PET-scans can provide ongoing pictures of the changes in brain activation over time (e.g. glucose uptake that occurs when an area of the brain needs oxygen for more strenuous activity), and thus could provide the best evidence of how language processing takes place dynamically. However the pictures PET-scans provide are much fuzzier than those of MRIs.

Currently many new imaging techniques are competing to provide crisp pictures of brain activities as they take place. One such solution is the evoked potential technique. This is used with normal subjects by attaching a number of electrodes on the scalp and then seeing which ones show electrical activity in the brain milliseconds after some stimulus has involved one or more areas of the brain that have thus emitted an electrical response. This technique is often abbreviated as ERP, standing for “event-related evoked potential.” The “event” is the stimulus; the evoked potential is the electrical response in the brain that can be read through the scalp.

A second imaging technique of interest is the fMRI, “functional
4 Aphasia: classification of the syndromes

Introduction

The human brain is well protected by the skull. Yet there are a number of possible ways for the brain to become injured. During a collision, the brain can be smashed against the skull with enough force to create a "closed head injury." Something (a bullet, knife, piece of metal, etc.) might strike the skull with enough force to penetrate it. Or the problem could originate inside the skull, with infection, tumor, or broken blood vessels damaging brain tissue. No matter what the cause of the brain injury, it is unlikely that the entire brain will be equally affected. Some areas will be "harder hit" than others.

When the brain is injured, the problems of the patient will vary depending on the extent and location of the damage. A particular injury might cause only visual problems or problems only in moving certain sets of muscles. The injuries of particular interest to us in this chapter are those that cause problems with language.

In our efforts to understand the brain representation for language, we will need to look carefully to see which locations in the brain will lead to language problems after injury and which locations will not. As noted earlier, language deficits acquired after brain injury are called "aphasia." We will see that not all "aphasics," that is, people with aphasia, have the same symptoms.

The most devastating kind of linguistic deficit is the total inability to communicate using language. The patient cannot speak more than a few words or syllables, and understands very little. When this type of deficit persists, it is referred to as "global aphasia" and is