

NEUROSCIENCE

6. NEUROLINGUISTICS

6.1. What is Neurolinguistics?

Neurolinguistics is the study of how language is represented in the brain. That is, how and where our brains store our knowledge of the language that we speak, understand, read, and write, what happens in our brains as we acquire that knowledge, and what happens as we use it in our everyday lives. Neurolinguists try to answer questions like these: What about our brains makes human language possible? Why is our communication system so elaborate and so different from that of other animals? Does language use the same kind of neural computation as other cognitive systems, such as music or mathematics? Where in your brain is a word that you've learned? How does a word 'come to mind' when you need it (and why does it sometimes not come to you)? If you know two languages, how do you switch between them and how do you keep them from interfering with each other? If you learn two languages from birth, how is your brain different from the brain of someone who speaks only one language, and why? Is the left side of your brain really the language side? If you lose the ability to talk or to read because of a stroke or other brain injury, how well can you learn to talk again? What kinds of therapy are known to help, and what new kinds of language therapy look promising? Do people who read languages written from left to right (like English or Spanish) have language in a different place from people who read languages written from right to left (like Hebrew and Arabic)? What about if you read a language that is written using some other kind of symbols instead of an alphabet, like Chinese or Japanese? If you're dyslexic, in what way is your brain different from the brain of someone who has no trouble reading? How about if you stutter? As you can see, neurolinguistics is deeply entwined with psycholinguistics, which is the study of the language processing steps that are required for speaking and understanding words and sentences, learning first and later languages, and also of language processing in disorders of speech, language, and reading.

6.2. How Does Neurolinguistics Work in the Brain?

Our brains store information in networks of brain cells (neurons and glial cells). These neural networks are ultimately connected to the parts of the brain that control our movements (including those needed to produce speech) and our internal and external sensations (sounds, sights, touch, and those that come from our own movements). The connections within these networks may be strong or weak, and the information that a cell sends out may increase the activity of some of its neighbors and inhibit the activity of others. Each time a connection is used, it gets stronger. Densely connected neighborhoods of brain cells carry out computations that are integrated with information coming from other neighborhoods, often involving feedback loops. Many computations are carried out simultaneously. As such, the brain is compared to being a massively parallel information processor.

Learning information or a skill happens by establishing new connections and/or changing the strengths of existing connections. These local and long-distance networks of connected brain cells show plasticity. That is, they can keep changing throughout our lives, allowing us to learn and to recover, to some extent, from brain injuries. For people with aphasia, which is language loss due to brain damage, depending on how serious the damage is, intense therapy and practice, perhaps in combination with transcranial magnetic stimulation (TMS), may bring about major improvements in language as well as in movement control. Computer-based methods for enabling such intense language practice under the supervision of a speech-language pathologist are also becoming available.

This question is hard to answer, because brain activity is like the activity of a huge city. A city is organized so that people who live in it can get what they need to live on, but you can't say that a complex activity, like manufacturing a product, is 'in' one place. Raw materials have to arrive at the right times, subcontractors are needed, the product must be shipped out in various directions. It's the same with our brains. We can't say that language is located in a particular part of the brain. It's not even true that a particular word is in one place in a person's brain. The information that comes together when we understand or say a word arrives from many places, depending on what the word means. For example, when we understand or say a word like apple, we are likely to use information about what apples look, feel, smell, and taste like, even though we aren't aware of doing this. So listening, understanding, talking, and reading involve activities in many parts of the brain. However, some parts of the brain are more involved in language than other parts.

Most of the parts of your brain that are crucial for both spoken and written language are in the left side of the cortex of your brain, called the left hemisphere, regardless of what language you read and how it is written. We know this because aphasia is almost always caused by left hemisphere injury, not by right hemisphere injury, no matter what language you speak or read, or whether you can read at all. This is true for about 95% of right-handed people and about half of left-handed people. A large part of the brain, the 'white matter', consists of fibers that connect different areas to one another, because using language and thinking requires the rapid integration of information that is stored and/or processed in many different brain regions.

Areas in the right side are essential for communicating effectively and for understanding the point of what people are saying. If you are bilingual but didn't learn both languages from birth, your right hemisphere may be somewhat more involved in your second language than it is in your first language. Our brains are somewhat plastic that is, their organization depends on our experiences as well as on our genetic endowment. For example, many of the auditory areas of the brain, which are involved with understanding spoken language in people with normal hearing, are used in visually understanding signed language by people who are deaf from birth or who became deaf early. And blind people use the visual areas of their brains in processing words written in Braille, even though Braille is read by touch. Bilingual speakers develop special skills in controlling which language to use and whether it is appropriate for them to mix their languages, depending on whom they are speaking to. These skills may be useful for other tasks as well.

6.3. The Development of Neurolinguistics

Many established ideas about neurolinguistics in particular, roles of the traditional language areas in the left hemisphere of the brain have been challenged and in some cases overturned by recent evidence. Probably the most important recent findings are 1) that extensive networks involving areas remote from the traditional language areas are deeply involved in language use 2) that the language areas are also involved in the processing of non-language information, such as some aspects of music 3) that the correlations of particular areas of the brain with particular language impairments are much poorer than had been thought. This new information has become available because of major improvements in our ability to see what is happening in the brain when people speak or listen, and from the accumulation and analysis of many years of detailed aphasia test data. For over a hundred years, research in neurolinguistics was almost completely dependent on

the study of language comprehension and production by people with aphasia. These studies of their language ability were augmented by relatively crude information about where the injury was located in the brain. Neurologists had to deduce that information, such as it was, by considering what other abilities were lost, and by autopsy information, which was not often available. A few patients who were about to undergo surgery to relieve severe epilepsy or tumors could be studied by direct brain stimulation, when it was medically needed to guide the surgeon away from areas essential for the patient's use of language.

Early-generation computerized x-ray studies (CAT scans, CT scans) and radiographic cerebral blood flow studies began to augment experimental and observational studies of aphasia, in the 1970s, but they gave very crude information about where the damaged part of the brain was located. These early brain imaging techniques could only see what parts of the brain had serious damage or restricted blood flow. They could not give information about the actual activity that was taking place in the brain, so they could not follow what was happening during language processing in normal or aphasic speakers. Studies of normal speakers in that period mostly looked at which side of the brain was most involved in processing written or spoken language, because this information could be gotten from laboratory tasks involving reading or listening under difficult conditions, such as listening to different kinds of information presented to the two ears at the same time, called dichotic listening.

Since the 1990s, there has been an enormous shift in the field of neurolinguistics. With modern technology, researchers can study how the brains of normal speakers process language, and how a damaged brain processes and compensates for injury. This new technology allows us to track the brain activity that is going on while people are reading, listening, and speaking, and also to get very fine spatial resolution of the location of damaged areas of the brain. Fine spatial resolution comes from magnetic resonance imaging (MRI), which gives exquisite pictures showing which brain areas are damaged. The resolution of CT scans has also improved immensely. Tracking the brain's ongoing activity can be done in several ways. For some purposes, the best method is detecting the electrical and magnetic signals that neurons send to one another by using sensors outside the skull (functional magnetic resonance imaging, fMRI; electro-encephalography, EEG; magnetoencephalography, MEG; and event-related potentials, ERP). Another method is observing the event related optical signal, EROS. This involves detecting rapid changes in the way that neural tissue scatters infrared light, which can penetrate the skull and see about an inch into the brain. A third family of methods involves tracking the changes in the flow of blood to different areas in the

brain by looking at oxygen concentrations (BOLD) or at changes the way in which the blood absorbs near infrared light (near-infrared spectroscopy, NIRS). Brain activity can also be changed temporarily by transcranial magnetic stimulation (stimulation from outside the skull, TMS), so researchers can see the effects of this stimulation on how well people speak, read, and understand language. NIRS, EROS, ERP, and EEG techniques are risk free, so they can ethically be used for research on normal speakers, as well as on people with aphasia who would not particularly benefit by being in a research study. TMS also appears to be safe.

It is very complicated to figure out the details of how the information from different parts of the brain might combine in real time, so another kind of advance has come from the development of ways to use computers to simulate parts of what the brain might be doing during speaking or reading. Investigations of exactly what people with aphasia and other language disorders can and cannot do also continue to contribute to our understanding of the relationships between brain and language. For example, comparing how people with aphasia perform on tests of syntax, combined with detailed imaging of their brains, has shown that there are important individual differences in the parts of the brain involved in using grammar. Also, comparing people with aphasia across languages shows that the various types of aphasia have somewhat different symptoms in different languages, depending on the kinds of opportunities for error that each language provides. For example, in languages that have different forms for masculine and feminine pronouns or masculine and feminine adjectives, people with aphasia may make gender errors in speaking, but in languages that don't have different forms for different genders, that particular problem can't show up.

6.4. Conditions

What is aphasia like? Is losing language after brain damage the reverse of learning it? People who have difficulties speaking or understanding language because of brain damage are not like children. Using language involves many kinds of knowledge and skill. People with aphasia have different combinations of things that they can still do in an adult like way and things that they now do clumsily or not at all. In fact, we can see different patterns of profiles of spared and impaired linguistic abilities across different people with aphasia. Therapy can help aphasic people to improve on or regain lost skills and make the best use of remaining abilities. Adults who have had brain damage and become aphasic recover more slowly than children who have had the same kind of damage, but they continue to improve slowly over decades if they have good language stimulation and do not

have additional strokes or other brain injuries.

What about dyslexia and children who have trouble learning to talk even though they can hear normally? Why do people have reading difficulties? Research suggests that dyslexics have trouble processing the sounds of language and have difficulty relating the printed word to sounds. Genetic differences and genetically-based brain differences have been found in families with dyslexia and developmental language disorders, and research in this area is helping us understand how genes act in setting up the initial wiring of all of our brains. There is solid evidence that appropriate language-based therapy is effective for children with developmental disorders of reading and language, including stuttering.