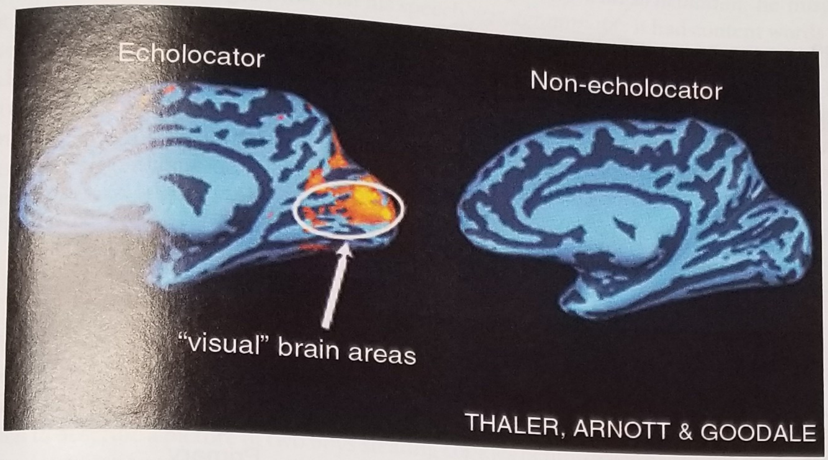
APPLICATION

I Hear a Tree Over There



Source: From "Neural Correlates of Natural Human Echolocation in Early and Late Blind Echolocation Experts," by Thaler, L., Arnott, S. R., and Goodale, M. A., 2011, *PLoS ONE* 6(5), e20162, doi: 10.1371/journal. pone.0020162.

Some blind individuals have a remarkable ability to avoid obstacles in their paths, often without any awareness of how they do so. In 1749, the French philosopher Denis Diderot (1916) studied one of these adept individuals and concluded that he relied on air currents deflected by the obstacles. By the time Karl Dallenbach and his colleagues tackled the question at Cornell University, 14 theories had been proposed (Supa, Cotzin, & Dallenbach, 1944) to explain how blind subjects could detect a wall from 4–17 feet away. They concluded that the subjects accomplished this by listening to the sounds of their footsteps reflected by the obstacle as they approached. Their performance was still surprisingly good when they listened from another room through headphones as an experimenter carrying a microphone walked toward the wall.

Blind individuals may use echolocation passively—simply listening for reflected sounds in their environment—or actively, by scuffing their feet or tapping a cane on the pavement, but these efforts can be thwarted by thick carpeting or a blanket of snow. Researchers have demonstrated that humans echolocate better when they actively vocalize instead of passively listen (Flanagin et al., 2017), and Daniel Kish is a living example of this principle. Daniel lost his eyes to cancer at the age of one, but he grew up surprisingly normally, even riding a bicycle to school (Kish, 2013). It wasn't until he was 11 that a friend pointed out to him that he was using echolocation, clicking his tongue two to three times a second and listening for the echoes. As an adult, he bikes in busy traffic, travels by plane without assistance, and hikes in the woods, where he can recognize trees by the difference in the way the leaves and the trunks reflect the sounds. An fMRI study showed that blind individuals engage part of the visual cortex during echolocation, an area that is well suited for processing spatial information (see figure; Thaler, Arnott, & Goodale, 2011).

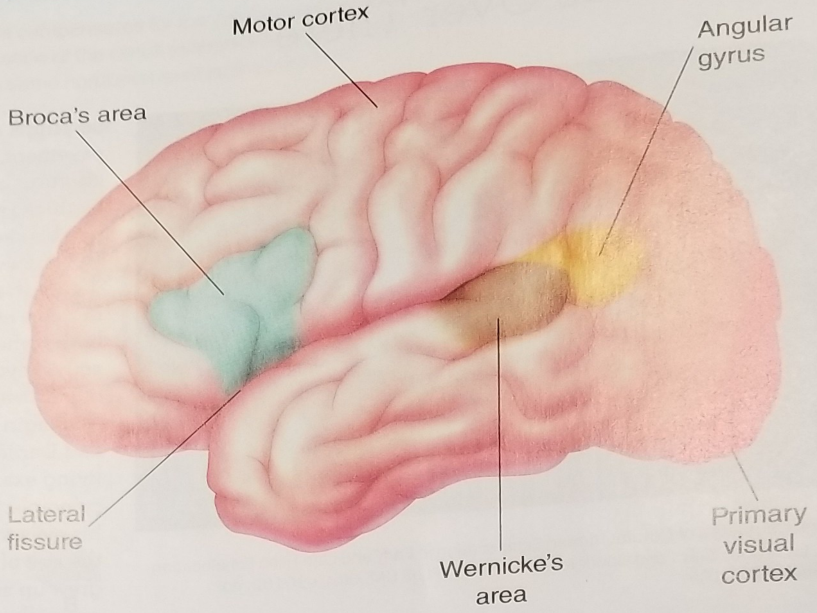
A team at University of California, Berkeley, took inspiration from bat echolocation to create a device that emits ultrasonic sweeps, whose echoes provide higher spatial resolution than sounds in our normal range of hearing; the device then converts the echoes to sound frequencies we can hear. Even untrained individuals could use the echoes to locate objects and determine their distance (Sohl-Dickstein et al., 2015).

Language

Now that we have gone over the basics of the auditory system, let's apply this knowledge to a behavior we all need to learn: language. Few would question the importance of language in human behavior. Keep in mind the meaning of the term *language:* It is not limited to speech but includes the generation and understanding of written, spoken, and gestural communication. Communication through language has important survival value and is inestimably important to human social relationships. A person who cannot communicate his or her thoughts to others suffers a high degree of isolation; one who cannot comprehend the communications of

> "*For humans, the most important aspect of hearing is its role in processing language.*
>
> *—A. J. Hudspeth*"

FIGURE 9.17 Language-Related Areas of the Cortex.



others is worse off still. These capabilities not only require learning; they also depend on specific structures of the brain, and damage to these structures can deprive a person of some or all of these functions.

Every language is characterized by a consistent set of rules, called grammar. This grammar can be quite flexible yet still convey the ideas and meaning of the speaker, which is called semantics. For instance, the *Star Wars* character Yoda frequently speaks with altered grammar in sentences like "See you I do," but the semantic meaning is clear. The individual sounds that comprise a language are called phonemes. Phonemes are small units of speech sound that distinguish one word from another—for example, the beginning sounds that distinguish *book, took,* and *cook.* Phonemes can be combinations of consonants and vowels (and even clicks!) and vary in languages from less than 20 in Polynesian languages (like Hawaiian) to over 80 in Taa (spoken in Botswana and Namibia).

In 1861, the French physician Paul Broca reported his observations of a patient who for 21 years had been almost unable to speak. Tan, as the hospital staff knew him because that was one of the few sounds he could make, died shortly after he came under Broca's care. The autopsy revealed that Tan's brain damage was in the posterior portion of the left frontal lobe. After studying eight other patients, Broca concluded that *aphasia*—language impairment caused by damage to the brain—results from damage to the frontal area anterior to the motor cortex, now known as *Broca's area.* Nine years later, a German doctor named Carl Wernicke identified a second site where damage produced a different form of aphasia. Located in the posterior portion of the left temporal lobe, this site is known as Wernicke's area. See Figure 9.17 to locate Broca's and Wernicke's areas and the other structures to be discussed here. Most of our understanding of the brain structures involved in language comes from studies of brain-damaged individuals, so this is where we will start.

Broca's Area

? What are the differences between Broca's aphasia and Wernicke's aphasia?

Broca's aphasia is language impairment caused by damage to Broca's area and surrounding cortical and subcortical areas. The symptoms can best be understood by examining the speech of a stroke patient; as you read this interview, you will see why the disorder is also referred to as *expressive aphasia.*

Doctor:	What happened to make you lose your speech?
Mr. Ford:	Head, fall, Jesus Christ, me no good, str, str . . . oh Jesus . . . stroke.
Doctor:	I see. Could you tell me, Mr. Ford, what you've been doing in the hospital?
Mr. Ford:	Yes, sure. Me go, er, uh, P.T. nine o'cot, speech . . . two times . . . read . . . wr . . . ripe, er rike, er, write . . . practice . . . getting better. (H. Gardner, 1975, p. 61)

Mr. Ford's speech was not nearly as impaired as Tan's; he can talk, and you can get a pretty good idea of his meaning, but he showed the classic symptoms associated with damage to Broca's area. First, his speech was *non-fluent*. Although well-practiced phrases such as "yes, sure" and "oh, Jesus" come out easily, his speech was halting, with many pauses between words. Second, he had trouble finding the right words, a symptom known as *anomia* ("without name"). He had *difficulty with articulation;* he mispronounced words, like "rike" for *write*. Finally, notice that his speech was *agrammatic;* it had content words (nouns and verbs) but lacked grammatical, or function, words (articles, adjectives, adverbs, prepositions, and conjunctions). The hardest phrase for a Broca's aphasic to repeat is "No ifs, ands, or buts" (Geschwind, 1972).

Broca believed that Broca's aphasia impaired motor instructions for vocalizing words. But Mr. Ford could recite the days of the week and the letters of the alphabet, or sing "Home on the Range." So, vocalization is not lost, but the ability to translate information into speech patterns is compromised. The problem is "upstream" from speech in the brain, so reading and writing are impaired as much as speech is. Comprehension is also as impaired as speech when the meaning depends on grammatical words. For example, the patient can answer questions like "Does a stone float on water?" but not the question "If I say, 'The lion was killed by the tiger,' which animal is dead?" (H. Gardner, 1975).

Wernicke's Area

In *Wernicke's aphasia,* the person has difficulty understanding and producing spoken and written language. This is often called *receptive aphasia,* but that term is misleading because the same problems with understanding language also show up in producing it. For example, the person's speech is *fluent* but meaningless. A patient asked to describe a picture of two boys stealing cookies behind a woman's back said, "Mother is away here working her work to get her better, but when she's looking the two boys looking in the other part. She's working another time" (Geschwind, 1979). This meaningless speech is called *word salad,* for obvious reasons.

Because the speech of the Wernicke's patient is articulate and has the proper rhythm, it sounds normal to the casual listener. The first time one of us met a person with Wernicke's aphasia, he was knocking on the social worker's door at the nursing home, and he thought it was because his thoughts were elsewhere that he failed to understand one of the residents when she spoke. But then his "Pardon me" elicited "She's in the frimfram," and he realized the problem was hers rather than his. He responded with a pleasantry, and she gave a classic word-salad reply. That began a long relationship of conversations, but the difference was that neither of us ever understood the other; another difference was that it did not matter, because she seemed strangely unaware that anything was amiss.

The Wernicke-Geschwind Model

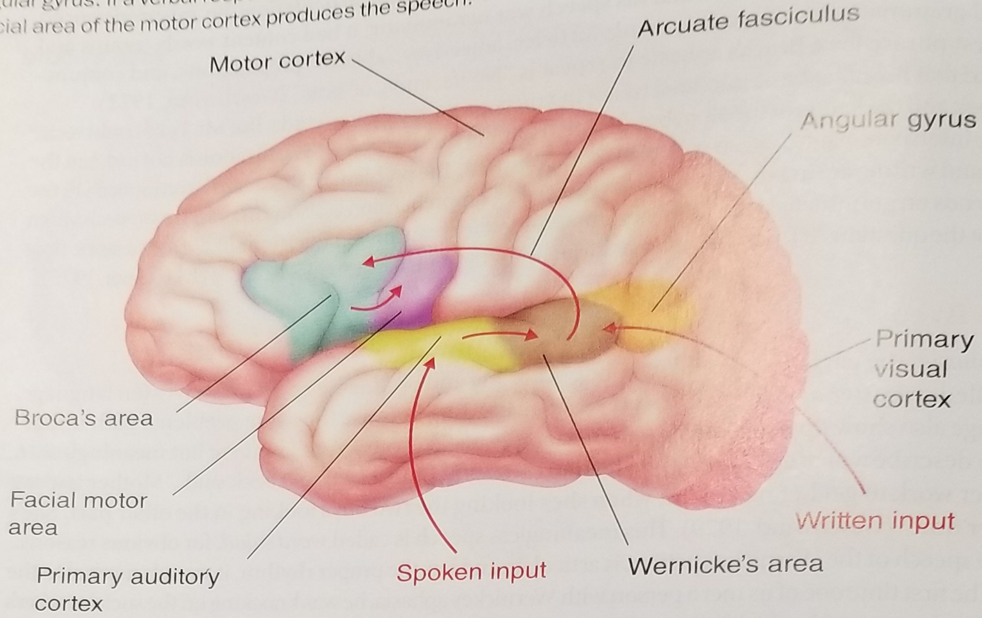
Of course, language requires more than just these two areas. Wernicke suggested, and Norman Geschwind later elaborated on, a model for how Broca's area and Wernicke's area interact to produce language (Geschwind, 1970, 1972, 1979). The model is illustrated in Figure 9.18 and in the following examples. Answering a verbal question involves a progression of activity from the auditory cortex to Wernicke's area, and then to Broca's area. Broca's area then formulates articulation of the verbal response and sends the result to the facial area of the motor cortex, which produces the speech. If the response is to be written, Wernicke's area sends output to the angular gyrus instead, where it elicits a visual pattern. When a person reads aloud, the visual information is translated into an auditory form by the angular gyrus and then passed to Wernicke's area, where a response is generated and sent to Broca's area for directing the muscles of the throat, mouth, and lungs. The idea that visual information must be converted to an auditory form for processing arose in part from the fact that language evolved long before writing was invented, and Wernicke's area was believed to operate in an auditory fashion.

This system has long been the primary model for how language operates. It is relatively simple and seems to explain the various aphasias. Modern imaging techniques have confirmed the participation of Broca's and Wernicke's areas in language. One study has traced the progression of activity while subjects produced a verbal response to written material, from the visual cortex to Wernicke's area and then to Broca's area (Dhond, Buckner, Dale, Marinkovic, & Halgren, 2001). However, there are problems. One is that language functions are not limited to Broca's and Wernicke's areas; damage to the basal ganglia, thalamus, and subcortical white matter also produce aphasias (Hécaen & Angelergues, 1964; Mazzocchi & Vignolo, 1979; Naeser et al., 1982). Broad cortical areas also play an important role, though possibly only because they are storage sites for information. For example, noun use (naming objects) produces activity just below the auditory cortex and Wernicke's area in the inferior/anterior temporal lobe (H. Damasio, Grabowski, Tranel, Hichwa, & Damasio, 1996). Verb use (describing what is happening in a picture) is impaired by damage to the left premotor cortex, which sends output to the motor cortex. This area is also activated while naming tools and by imagining body movements (Hauk, Johnsrude, & Pulvermüller, 2004). Apparently when tool names are learned, they are stored near the brain structure that would produce the action. And there is evidence that object categories are stored in different areas as well (Caramazza & Mahon, 2006).

FIGURE 9.18 The Wernicke-Geschwind Model of Language.

Verbal input arrives in the auditory cortex and then travels to Wernicke's area for interpretation. Written input arrives there via the visual cortex and angular gyrus. If a verbal response is required, Wernicke's area sends output to Broca's area for articulation of the response, and the facial area of the motor cortex produces the speech.

Figures Brought to Life



Source: Adapted from "Specializations of the Human Brain," by N. Geschwind, *Scientific American*, 241(9), pp. 180–199.

Electrical stimulation studies (Mateer & Cameron, 1989; Ojemann, 1983) and studies of brain damage (Hécaen & Angelergues, 1964) have also shown that the various components of language functioning are scattered throughout all four lobes (Figure 9.19). This does not mean that there is no specialization of the cortical areas; for example, articulation errors are still more likely to result from frontal damage and comprehension problems from damage in the temporal lobes (Hécaen & Angelergues; Mazzocchi & Vignolo, 1979). However, it does mean that each function depends on a network of interconnected structures rather than a single structure. We do know that, like vision, there are processing streams in the cortex devoted to language. The dorsal stream passes through frontal sensorimotor areas that deal with planning speech, rhyming, and working memory, whereas the ventral stream that passes through the left temporal gyrus helps us comprehend language (Hickok & Poeppel, 2007).

Other challenges to classic theory include studies that question, for example, how the language structures are interconnected (Dick & Tremblay, 2012), indicating that spoken words are processed anterior to the auditory cortex rather than in Wernicke's area (DeWitt & Rauschecker, 2012). The Wernicke-Geschwind view therefore has turned out to be too simple, but it has also helped researchers organize their thinking about language and has generated volumes of research—which, after all, is how we make scientific sense of our world.

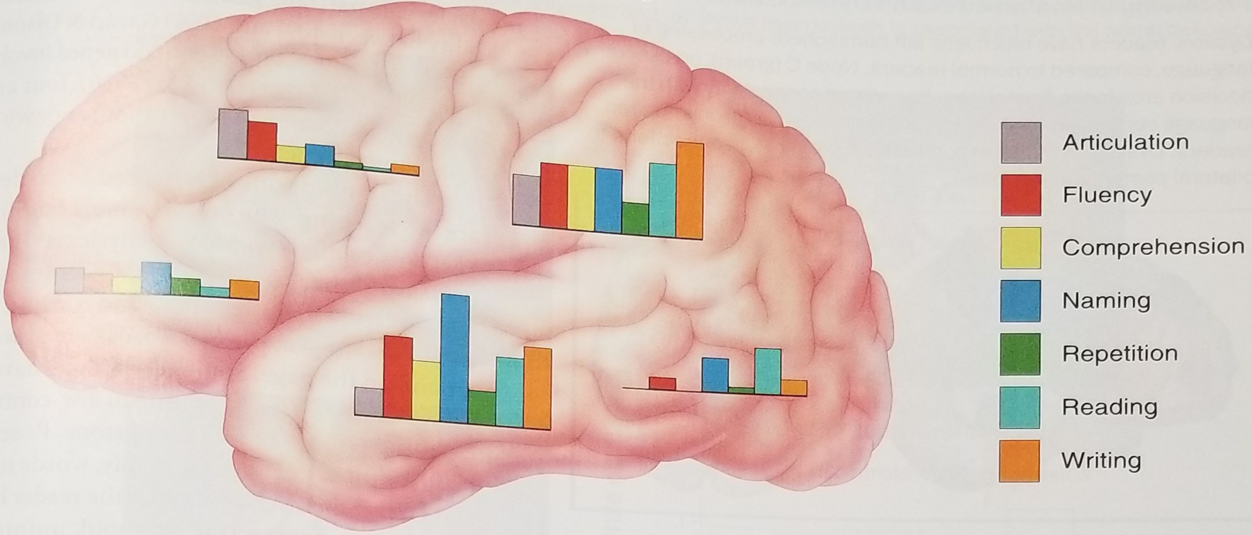
Reading, Writing, and Their Impairments

Although aphasia affects reading and writing, these functions can be impaired independently of other language abilities when the visual inputs to the language network are interrupted. In language disorders, a complete absence of behavior has the prefix "a-," while impairment of behavior has the prefix "dys-." *Alexia* is the inability to read, and *agraphia* is the inability to write. Presumably, they are due to disruption of pathways in the *angular gyrus* that connect the visual projection area with the auditory and visual association areas in the temporal and parietal lobes (see Figure 9.17 again). The PET scans in Figure 9.20 show that activity increases in this area during reading.

Reading and writing are also impaired in learning disorders. The most common learning disorders are *dyslexia*, an impairment of reading; dysgraphia, difficulty in writing; and *dyscalculia*, a disability with

FIGURE 9.19 Frequency of Language Deficits Resulting From Damage in Each Area.

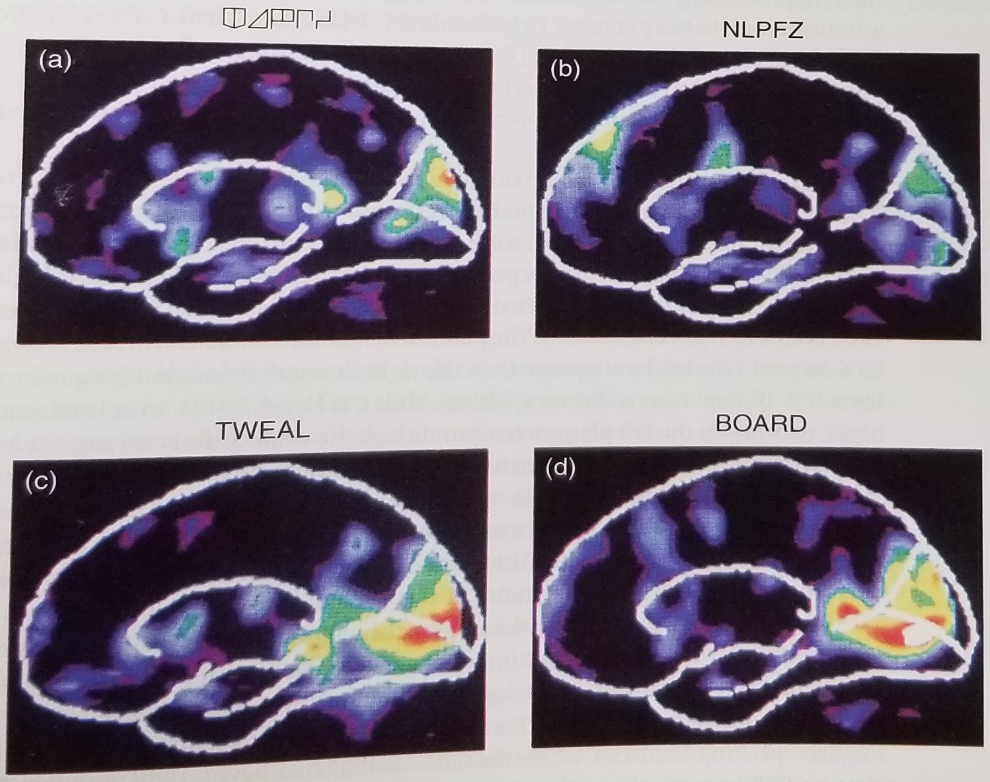
Language functions are more widely distributed than originally thought.



Source: Based on Hécaen and Angelergues (1964).

FIGURE 9.20 PET Scans During Reading.

Viewing letterlike forms (a) and strings of consonants (b) did not activate the area between the primary visual cortex and language areas, but reading pronounceable nonwords (c) and real words (d) did.



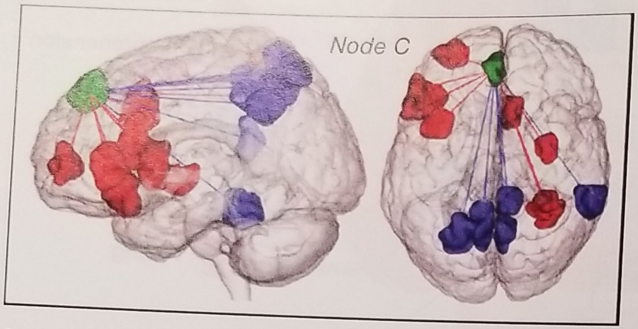
Source: From “Activation of Extrastriate and Frontal Cortical Areas by Visual Words and Word-Like Stimuli,” S. E. Petersen, P. T. Fox, A. Z. Snyderand, and M. E. Raichle, *Science, 249*, pp. 1049–1044. Reprinted with permission from AAAS.

arithmetic. Because of its importance and the amount of research that has been done, we will focus on dyslexia. Dyslexia can be *acquired*, through damage, but its origin is more often *developmental*. Developmental dyslexia is partially genetic, with an estimated heritability between 40% and 60% (Gayán & Olson, 2001). Of the seven most reliably identified genes involved in dyslexia (Scerri & Schulte-Körne, 2010), four are involved in neuron guidance and migration, and two contribute to cell functioning.

The implications of impaired brain development are far-reaching. The public is most familiar with the *visual-perceptual* symptoms of dyslexia: The individual reads words backwards ("now" becomes "won"), confuses mirror-image letters (*p* and *q*, *b* and *d*), and has trouble fixating on printed words, which seem to move around on the page. Some researchers have attributed this to slowness in responding to low-contrast, rapidly changing visual stimuli (Livingstone, Rosen, Drislane, & Galaburda, 1991); presumably, words jump around and reverse themselves because the reader has difficulty detecting and correcting for rapid, unintentional eye movements (called saccades), which affects both reading performance and learning to read in the first place (Bucci, Bremond-Gignac, & Kapoula, 2008).

FIGURE 9.21 Left- Versus Right-Hemisphere Language Processing in Nonimpaired and Dyslexic Readers.

Dyslexic readers have much less left hemisphere processing of language, compared to normal readers. Node C (green), an executive decision area in the frontal lobe, has strong connectivity with the language centers on the left side of the brain (red) in non-impaired readers. Dyslexic readers, in contrast, have stronger connections to bilateral posterior areas (blue).



Source: Figure 3C from "Disruption of Functional Networks in Dyslexia: A Whole-Brain, Data-Driven Analysis of Connectivity," by E. S. Finn, X. Shen, et al., 2014, *Biological Psychiatry*, 76, pp. 397–404. With permission from Society of Biological Psychiatry.

However, individuals with dyslexia also have trouble tracking the frequency and amplitude changes that distinguish speech sounds from each other (J. Stein, 2001); supposedly this impairs the dyslexic's ability to associate speech sounds with letters when learning to read and explains his or her slowness in reading nonwords. According to the *phonological hypothesis,* individuals with dyslexia have impairment in processing, storing, and/or retrieving phonemes. When a group of dyslexic college students was administered a battery of tests, 10 had auditory deficits and 2 had a visual function deficit, but all 16 suffered from a phonological deficit (Ramus et al., 2003). Almost all researchers in the field now agree that phonological impairment is the crucial problem, and even suggest that at least some of the visual processing problems are a consequence, rather than a cause, of reading impairment (Habib, 2003; Olulade, Napollello, & Eden, 2013).

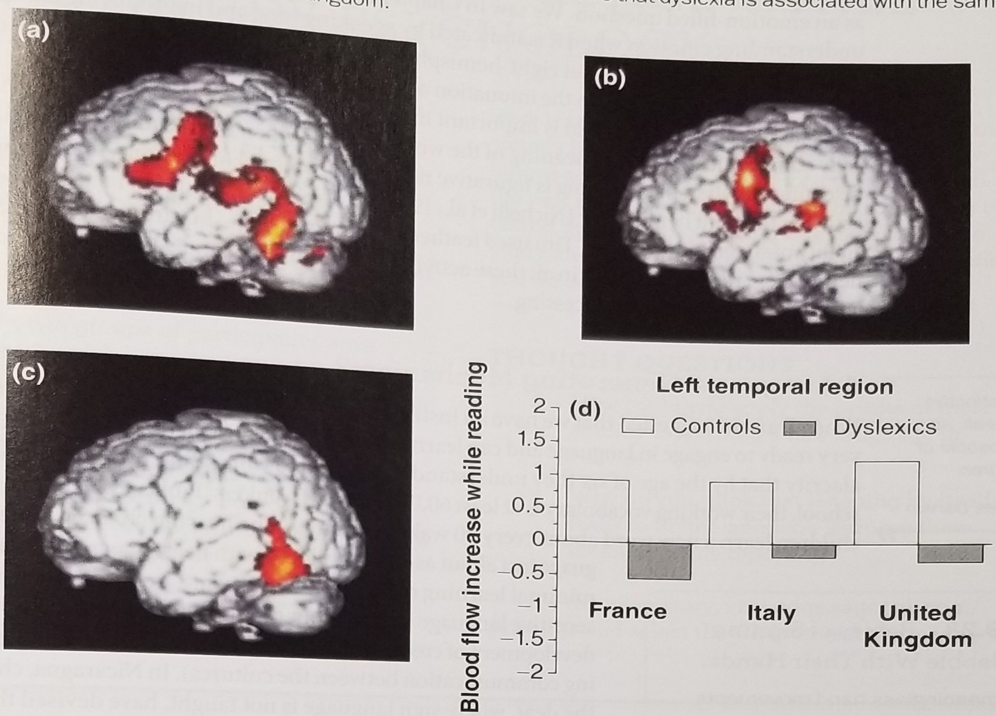
? What problems have been found in the brains of people with dyslexia?

These difficulties are accompanied by several functional and structural irregularities in the brain. Kindergartners who had a delayed EEG response when a string of repeated auditory or speech sounds was interrupted by a novel sound were more likely to have reading difficulties in the fifth grade (Maurer et al., 2009). In addition, kindergartners who scored poorly on a phonological awareness test used to measure risk for dyslexia had a smaller left arcuate fasciculus, which connects Wernicke's area with Broca's area (Saygin et al., 2013). The *planum temporale,* where Wernicke's area is located, averages about 13% larger in the left hemisphere than the right in nondyslexics but is equally sized in people with dyslexia (J.S. Bloom, Garcia-Barrera, Miller, Miller, & Hynd, 2013). In at least some dyslexic brains, many of the neurons in the left planum temporale lack the usual orderly arrangement, and some of them have migrated past their normal destination and into the outermost layer of the cortex (Galaburda, 1993). One study found that young individuals with dyslexia must "sound out" the words in their minds, rather than visually recognizing the words in a much faster fashion, due to reduced connections in the left word form areas (Figure 9.21; Finn et al., 2014). These brain anomalies suggest that at least some of the origins of developmental dyslexia are prenatal.

The incidence of dyslexia is twice as great in some cultures as in others; this seems to suggest a cultural explanation for the disorder, but in fact the discrepancies support a brain-based phonological hypothesis. Italian and Spanish are phonologically simpler languages, with an almost one-to-one correspondence between phonemes and spelling. Predictably, dyslexia is much rarer in Italy and Spain than in French- and English-speaking countries, where the same spelling may have several pronunciations (*cough, tough, dough, slough*). PET imaging shows that Italians suffering from dyslexia have the same brain impairments seen in French and English speakers (Figure 9.22; Paulesu et al., 2001).

FIGURE 9.22 Activation of Language Areas in Individuals With Dyslexia From Three Countries.

Here (a) shows activation due to reading in control subjects; (b) shows activation due to reading in dyslexics; (c) indicates the area significantly less activated in dyslexics than in control subjects; and (d) shows that dyslexia is associated with the same deficiency in individuals from France, Italy, and the United Kingdom.



Source: From "Dyslexia: Cultural Diversity and Biological Unity," by E. Paulesu, J.-F. Démonet, F. Fazio, E. McCrory, V. Chanoine, N. Brunswick, S. F. Cappa, G. Cossu, M. Habib, C. D. Frith, and U. Frith, *Science, 291*, pp. 2165–2167. Reprinted with permission from AAAS.

Recovery From Aphasia and Lateralization of Language

There is usually some recovery from acquired aphasia during the first one or two years, more so for Broca's aphasia than for Wernicke's aphasia (I. P. Martins & Ferro, 1992). Initial improvement is due to reduction of the swelling that often accompanies brain damage rather than to any neural reorganization. Just how the remaining recovery occurs is not well understood, but it is a testament to the brain's plasticity.

The right hemisphere can take over language functions following left-hemisphere damage, if the injury occurs early in life. A two-year-old girl had a left-hemisphere stroke; her language was impaired, but she developed normal language capability by the age of seven. Then at the age of 56, she had a right-hemisphere stroke, which resulted in a second aphasia from which she had only minimal recovery (Guerreiro et al., 1995). Right-hemisphere language was confirmed by fMRI in all five individuals of a group who had been born with inadequate blood supply to the language areas of the left hemisphere (Vikingstad et al., 2000). Rasmussen and Milner (1977) used the *Wada technique* and electrical stimulation to determine the location of language control in patients before removing lesioned tissue that was causing epileptic seizures. (The Wada technique involves anesthetizing one hemisphere at a time by injecting a drug into each carotid artery; when the injection is into the language-dominant hemisphere, language is impaired.) Individuals whose left-hemisphere injury occurred before the age of five were more likely to have language control in the right hemisphere, supporting the hypothesis of right-hemisphere compensation. Patients whose left-hemisphere damage occurred later in life more often continued to have language control in the left hemisphere; there was, however, evidence in some cases that control had shifted into the border of the parietal lobe. Since language functions are scattered widely in the left hemisphere, perhaps the compensation involves enhancing already-existing activity rather than establishing new functional areas.

The ability of the right hemisphere to assume language functions may result in part because it normally makes several contributions to language processing. The most obvious right-hemisphere role in language is *prosody*, the use of intonation, emphasis, and rhythm to convey meaning in speech. An example of one aspect of prosody is the *difference* between "You put the cat out when it's freezing" spoken as a statement and spoken as an emotion-filled question. We saw in Chapter 8 that people with right-hemisphere damage have trouble understanding emotion when it is indicated by speaking tone and in producing emotional speech the same way. An fMRI study found that right-hemisphere activity increased while individuals detected angry, happy, sad, or neutral emotions from the intonation of words (Buchanan et al., 2000).

The right hemisphere also is important in understanding information from language that is not specifically communicated by the meaning of the words, such as when the meaning must be inferred from an entire discourse or when the meaning is figurative rather than literal. For example, interpreting the moral of a story activates the right hemisphere (Nichelli et al., 1995), as does understanding a metaphor or determining the plausibility of statements such as "Tim used feathers as paperweights" (Bottini et al., 1994). Interestingly, the right-hemisphere regions involved in all these activities correspond generally to the structures we have identified in left-hemisphere language processing.

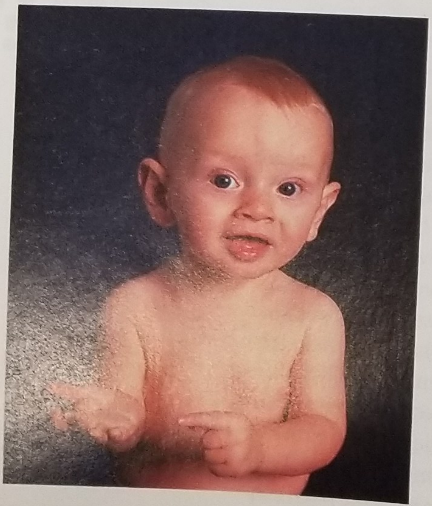
> "Man has an instinctive tendency to speak, as we see in the babble of our young children.
>
> —Charles Darwin"

A Language-Generating Mechanism?

When Darwin suggested that we have an instinctive tendency to speak, what he meant was that infants seem very ready to engage in language and can learn it with minimal instruction. Children learn language with such alacrity that by the age of six they understand about 13,000 words, and by the time they graduate from high school, their working vocabulary is at least 60,000 words (Dronkers, Pinker, & Damasio, 2000). This means that children learn a new word about every 90 waking minutes. The hearing children of deaf parents pick up language just about as fast as children with hearing parents (Lenneberg, 1969), despite minimal learning opportunities. Not only are preadolescent children particularly sensitive language learners, but they are also believed to be the driving force in the development of creole language (which combines elements of two languages, allowing communication between the cultures). In Nicaragua, children in the school for the deaf, where sign language is not taught, have devised their own sign language with unique gestures and grammar (Senghas, Kita, & Özyürek, 2004).

FIGURE 9.23 Babies of Signing Parents Babble With Their Hands.

Unlike the meaningless hand movements of other infants (which they also make at other times), their babbling is like their parents' signing. Babbling hand movements are slower and restricted to the space in front of the infants' bodies, and they correspond to the rhythmic patterning of adult sign-syllables.



Source: Petitto, Holowka, Sergio, & Ostry, "Language rhythms in baby hand movements." *Nature*, 413, 35–36. Photo courtesy of Dr. Laura-Ann Petitto, University of Toronto.

Noam Chomsky (1980) and later Steven Pinker (1994) interpreted children's readiness to learn language as evidence of a *language acquisition device*, a hypothesized part of the brain dedicated to learning and controlling language. Not all researchers agree with this idea (see below), but most accept that there are biological reasons why language acquisition is so easy. This ease cuts across forms of language. For example, both hearing and deaf infants of signing parents babble in hand movements (Figure 9.23); the deaf infants' babbling proceeds into signing through the same stages and at about the same pace that children of speaking parents learn vocal language (Petitto, Holowka, Sergio, & Ostry, 2001; Petitto & Marentette, 1991). The researchers suggest that the ease of children's language acquisition is due to a brain-based sensitivity to rhythmic language patterns, a sensitivity that does not depend on the form of the language. Rhythm problems in childhood appear to correlate to reading disorders as adults (K. W. Carr, White-Schwoch, Tierney, Strait, & Kraus, 2014). And new evidence suggests that when musicians improvise passages within a larger ensemble, they use language centers as if they are participating in a musical conversation with the group (Donnay, Rankin, Lopez-Gonzalez, Jiradejvong, & Limb, 2014). As the accompanying In the News feature explains, we are predisposed to learn language as adults, even when we are not focused on it.

Innate Brain Specializations

More than 90% of right-handed people are left-hemisphere dominant for language. This is also true for two-thirds to three-quarters of left-handers; the remainder is about equally divided between right-hemisphere dominant and mixed (Knecht et al., 2000; B. Milner, 1974). In the large majority of autopsied brains, the left-hemisphere Broca's area is larger (Falzi, Perrone, & Vignolo, 1982), and the lateral fissure (Yeni-Komshian & Benson, 1976) and planum temporale

IN THE NEWS

LEARN A NEW LANGUAGE WHILE YOU STUDY PSYCHOLOGY

How would you like to learn a new language while doing your psychology homework? We have been told since we were young that we had to focus and practice to learn how to speak another language, but recent evidence suggests that our brains are just as good at acquiring language information passively when we divert our attention elsewhere (reported in Greenwood, 2017).

In one study, two groups of participants were trained to distinguish between several similar-sounding phonemes of native Hindi speakers. The focus group practiced for one continuous hour across two days, while the other group alternated between 10 minutes of active practice and 10 minutes of another task for an hour while the sounds continued in the background. Surprisingly, the researchers discovered the "distracted" group learned the discrimination task as well as the "focused" group. In another study, students who were learning Spanish learned to distinguish among sounds better if they simply listened to the new language rather than trying to speak along with the new material. So there might be something to taking frequent breaks from intensive language study and turn on a movie in that language while you do something else.

THOUGHT QUESTIONS

1. How could you apply the results of these studies to learning a new language in college?
2. Why do you think that listening by itself leads to better language learning than listening while repeating?

For the news story, visit edge.sagepub.com/garrett5e and select the Chapter 9 study resources.

(Geschwind & Levitsky, 1968; Rubens, 1977; Wada, Clarke, & Hamm, 1975) are longer. These differences are not the result of usage. By the 20th week of gestation, the left temporal lobe is already beginning to enlarge relative to the right (Kasprian et al., 2010), and the left planum temporale is larger by the 29th week (Wada et al., 1975). At birth or shortly after, speech causes a greater increase in cerebral blood flow than nonspeech sounds, speech sounds activate the same left-hemisphere language areas as in adults, and sentence melody activates the right hemisphere (reviewed by Friederici, 2006). Congenitally deaf individuals also have larger left temporal lobes, though the lack of auditory experience does result in fewer connections between language areas and auditory centers (Shibata, 2007).

Storing Multiple Languages

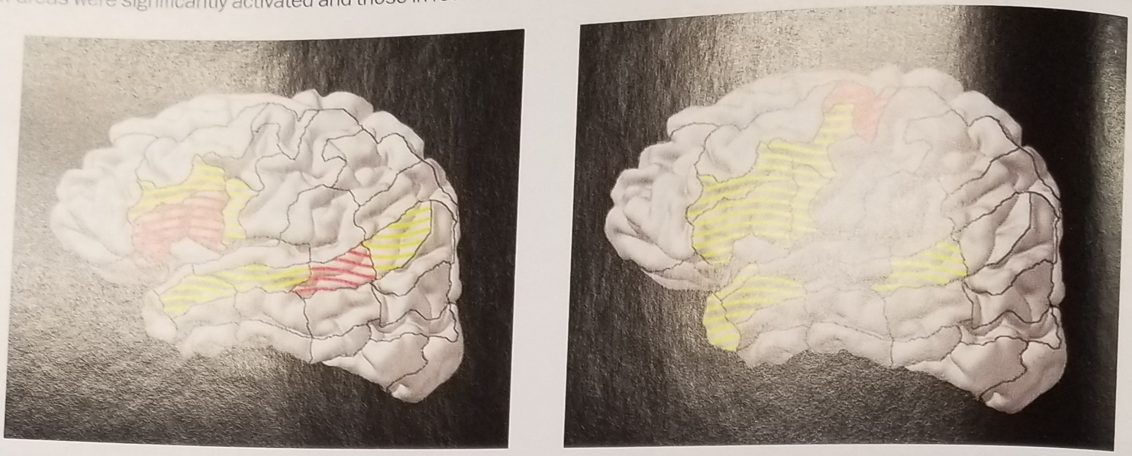
Additional evidence for a language acquisition device comes from studies of individuals who communicate with sign language. Left-hemisphere damage impairs sign-language ability more than right-hemisphere damage does (Hickok, Bellugi, & Klima, 1996), and communicating in sign language activates the classical left-hemisphere language areas (Figure 9.24; Neville et al., 1998; Petitto et al., 2000). This was true of both congenitally deaf and normally hearing signers (all of whom had used sign language from infancy), but the finding is especially interesting in the deaf individuals, because it cannot be the result of the brain simply using pathways already established by an auditory language. It is also interesting because Wernicke's area has traditionally been considered auditory in nature, which required the conversion of written words into an auditory form. Either the posterior language area is inherently more versatile than some theorists have thought, or the area underwent reorganization during infancy that enabled it to handle visual language.

Either way, language seems to be a specialized capability of a limited subset of brain structures.

But what happens if a person learns a second language after childhood, when the brain is less plastic (Figure 9.25); will the brain then recruit other areas to handle the task? Two imaging studies indicate that this does happen, to some extent. In the first study, bilingual individuals silently "described" events from the previous day in each of their two languages; the languages activated separate areas in the frontal lobes, with centers that were 4.5–9 mm apart in different individuals. This was not true of subjects who learned their second

FIGURE 9.24 Language Areas in Hearing and Deaf Individuals.

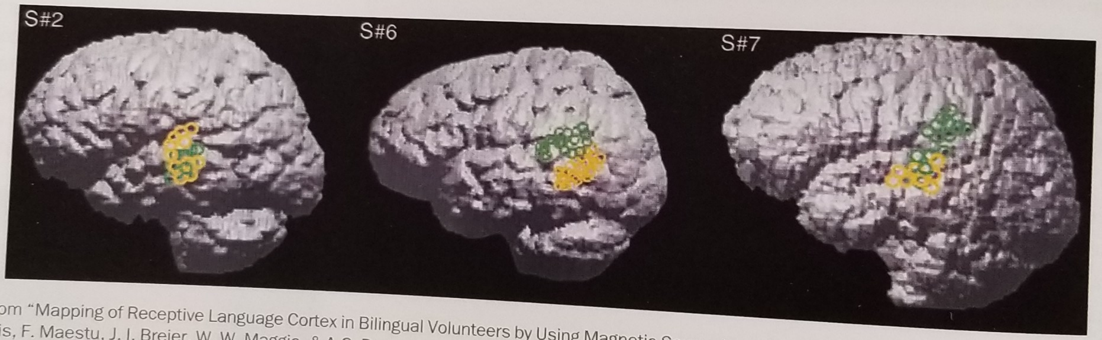
(a) fMRI results while hearing subjects read written English. (b) Activation in subjects deaf from birth while processing sign language. Yellow areas were significantly activated and those in red more so.



Source: From "Cerebral Organizations for Language in Deaf and Hearing Subjects: Biological Constraints and Effects of Experience," by H. J. Neville et al., 1998, *Proceedings of the National Academy of Sciences, USA*, 95, pp. 922–929. © 1998 National Academy of Sciences, U.S.A.

FIGURE 9.25 Brain Areas Activated by Different Languages in Bilingual Individuals.

Green circles represent areas activated by listening to English, and yellow circles indicate activation while listening to Spanish. These images are from different subjects, selected to represent the variability among 11 subjects. Although the patterns are different, in every case the languages activate separate areas.



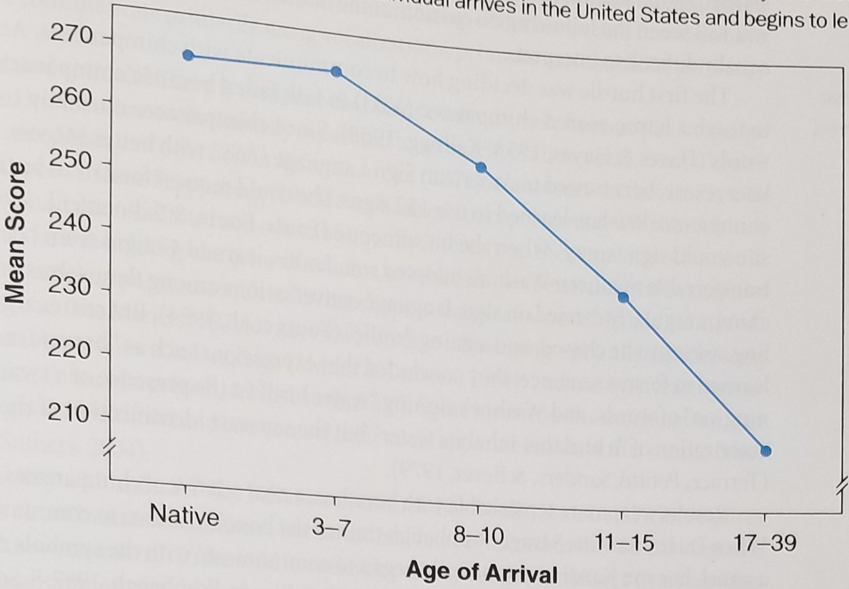
Source: From "Mapping of Receptive Language Cortex in Bilingual Volunteers by Using Magnetic Source Imaging," by P. G. Simos, E. M. Castillo, J. M. Fletcher, D. J. Francis, F. Maestu, J. I. Breier, W. W. Maggio, & A.C. Papanicolaou, 2001, *Journal of Neurosurgery*, 95, pp. 76–81.

language simultaneously with the first (K. H. S. Kim, Relkin, Lee, & Hirsch, 1997). The second study produced similar results in the temporal lobe when subjects heard and read words in their two languages (Figure 9.26; Simos et al., 2001). This separation is so distinct that capability can be impaired in one of the languages while the other is unaffected (called bilingual aphasia; Gomez-Tortosa, Martin, Gaviria, Charbel, & Auman, 1995; M. S. Schwartz, 1994). A colleague who is originally from Lebanon told one of us an interesting story about his mother. She lives in the United States, and she was fluent in English until a stroke impaired her ability to speak English, but not Arabic. Her nearby family members spoke only English, so when they needed to talk with her they had to telephone a relative in another city to translate! These observations are not as inconsistent with the hypothesis of a single language acquisition device as they might seem. In both the K. H. S. Kim et al. (1997) and the Simos et al. (2001) studies, the second-language locations were in the same area as Broca's and Wernicke's areas, respectively.

We still cannot say that they evolved specifically to serve language functions. You will see in the next section that some primates show similar enlargements in the left hemisphere, and their possession of language is

FIGURE 9.26 The Critical Period of Language Acquisition.

Children can readily learn new languages when young, but they slowly lose this ability starting at puberty. The mean score is a relative measure of English mastery; the age of arrival is when the individual arrives in the United States and begins to learn English.



Source: From "Critical period effects in second language learning: the influence of maturational state on the acquisition of English as a second language," by J. S. Johnson & E. L. Newport, 1989, *Cognitive Psychology*, 21, pp. 60–99.

questionable at best. A reasonable interpretation of these data is that certain brain areas evolved simply to handle rapidly changing information and complex discriminations, which language in its various forms requires. The strongest proponent of this "language as use" theory is Vyvyan Evans, who cites agrammatic languages in native Australia, and the lack of new spontaneous languages forming in isolated groups of humans, as evidence that language may simply be the result of our vast capacity to learn. Another view is that the language areas are primarily specialized for different aspects of general learning: the frontal area for "procedural" or how-to learning that coincides with the rules of grammar and verb tenses, and the temporal area for "declarative" or informational learning and, thus, the storage of word meanings and information about irregular word forms (Ullman, 2001). Even if these learning structures have been "borrowed" to serve language functions and the concept of a dedicated language acquisition device isn't meaningful, it is still clear that the human brain is uniquely well fitted for creating, refining, and learning language. We will explore the possible evolutionary roots of this ability in the context of animal language.

Language in Nonhuman Animals

Research has refuted most of humans' claims to uniqueness, including tool use, tool making, and self-recognition. Determining whether we have exclusive ownership of language has been more difficult. Animal language intrigues us both because we're curious whether we have any company "at the top" and because we want to trace the evolutionary roots of language. Because language (like all behaviors) leaves no fossils behind, the origin of language is "a mystery with all the fingerprints wiped off" (Terrence Deacon, quoted by Holden, 2004a). Without this evidence, we are left with comparing the behavior and brains of our nonhuman relatives. The rationale behind animal language research is that any behavior or brain mechanism we share with other animals must have originated in common ancestors, or through similar mechanisms. Although dolphins, whales, and gorillas have been the subjects of mammalian research, the major contenders for a coprocessor of language have been the chimpanzee and bonobo. The reason is that humans and these ape species diverged from common ancestors a relatively recent 5 million years ago and we still share 99% of our genetic material (Prufer et al., 2012).

skills have
ps achieved
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A major obstacle has been deciding what we mean by *language*. Linguists agree that the vocalizations animals use to announce intentions or states (like finding food, detecting danger, and being hungry) are only signals and have little to do with language. Even the human toddler's request of "milk" may initially be just a learned signal to indicate hunger and, like the monkey's alarm call, indicate no language understanding. As you will see in the following discussion, some of the results obtained in language research with animals are equally difficult to interpret.

The first hurdle was deciding how to communicate with chimpanzees. An early study that attempted to teach a home-reared chimpanzee (Viki) to talk failed because chimpanzees lack a larynx for forming words (Hayes & Hayes, 1953; Kellogg, 1968). Since chimpanzees normally communicate using gestures, later researchers turned to American Sign Language (ASL) with better success. Over a four-year period, the chimpanzee Washoe learned to use 132 signs; she could request food or to be tickled or to play a game, and she would sign "sorry" when she bit someone (Fouts, Fouts, & Schoenfeld, 1984). And these gestures were transferrable to others: Washoe's adopted son, Loulis, learned 47 signs from her and three other chimps. The chimps regularly carried on sign-language conversations among themselves, most requesting hugs or tickling, asking to be chased, and signing "smile" (Fouts et al., 1984). But critics argued that no chimpanzee had learned to form a sentence; they concluded that expressions such as "banana me eat banana" are just a "running-on" of words, and Washoe's signing "water bird" in the presence of a swan was not the inventive characterization of "a bird that inhabits water" but the separate identification of the bird and the water it was on (Terrace, Petitto, Sanders, & Bever, 1979).

Results were more remarkable with bonobos, a near relative of chimpanzees and equally close to humans. When Duane and Sue Savage-Rumbaugh trained the bonobo Mutata to communicate by pressing symbols on a panel, her son Kanzi spontaneously began to communicate with the symbols and eventually learned 150 of them without any formal instruction (Figure 9.27; S. Savage-Rumbaugh, 1987; S. Savage-Rumbaugh, McDonald, Sevcik, Hopkins, & Rubert, 1986). Kanzi uses the board to request specific food items or to be taken to specific locations on the 55-acre research preserve, asks one person to chase a specific other person, and responds to similar requests from trainers. His communication skills have been estimated at the level of a two-year-old child (E. S. Savage-Rumbaugh et al., 1993).

Clearly, chimps and bonobos use predominantly gestural communication mechanisms, while we use a vocal mechanism. How did our spoken language evolve from a gestural one? There are two theories that have the most support. One theory, described by Corballis (2002), suggests that vocal language was a replacement for gestural language, to communicate over longer distances. Another theory, put forth by Dunbar (1996),

E 9.27 Language Research With Chimpanzees and Bonobos.

archer converses with a chimp using American Sign Language. (b) A bonobo communicates through the symbol board.

suggests a more social role in communication; as groups of apes grew large, the grooming signals used to bond with others were replaced by vocal ones so that the hands could be used for other things like foraging. Dunbar's theory explains why most of us are right-handed and why speech is processed in the left hemisphere—gestural language controlled by the left hemisphere became vocal language in the same areas. Taken together, both theories explain why our greatest successes in communicating with chimps and bonobos have come through ASL—while we communicate primarily using vocalizations, primates communicate primarily using gestures.

What about other, nonrelated animals? There is evidence that birds evolved a very human-like language system, even though birds and humans are evolutionarily separated by over 350 million years. Even Charles Darwin, in his book *The Descent of Man and Selection in Relation to Sex* (1871), comments on the similarities between birdsong and human speech. Irene Pepperberg (1993) emphasized concept learning with her African gray parrot, Alex, but his communication skills turned out to be equally interesting. Using speech, Alex could tell his trainer how many items she was holding, the color of an item, or whether two items differed in shape or color. He also could respond to complex questions, such as "What shape is the green wood?" In addition, birds learn language in similar ways to us (see Marler, 1997, for a review); birds can have geographically distinct song *dialects*, which are regionally stable variations in language (Marler & Tamura, 1964); and can even learn grammatical patterns like us (Gentner, Fenn, Margoliash, & Nusbaum, 2006). Some birds, like the mockingbird, can even learn new "words" throughout adulthood and can control their vocal apparatus in ways that mimic other species' patterns (Zollinger & Suthers, 2004).

So do we share language ability with animals? The behavior of animals like Loulis, Kanzi, and Alex requires us to rethink our assumptions about human uniqueness, but no animal has yet turned in the critical language performance, and as far as we know, no animals in the wild have developed anything resembling a true language. But what some researchers do see in the animals' performance is evidence of evolutionary foundations of our language abilities (Gannon, Holloway, Broadfield, & Braun, 1998).

Neural and Genetic Antecedents

An approach of some researchers has been to determine whether other animals share with us any of the brain organization associated with human language. The results have been intriguing. In the chimpanzee, as with humans, there is a greater ratio of white to gray matter in the left hemisphere than in the right (Cantalupo et al., 2009), and the left lateral fissure is longer and the planum temporale is larger (Gannon et al., 1998; Yeni-Komshian & Benson, 1976). Japanese macaque monkeys respond better to calls of their own species when the recorded calls are presented through headphones to the right ear (and, therefore, primarily to the left hemisphere) than when they are presented to the left ear. There is no left-hemisphere advantage for the (nonmeaningful) calls of another monkey species (M. R. Petersen, Beecher, Zoloth, Moody, & Stebbins, 1978). Dolphins and the Rumbaughs' chimps Austin and Sherman responded more quickly when symbols or command gestures were presented to their left hemisphere (Hopkins & Morris, 1993; Morrel-Samuels & Herman, 1993). Songbirds and parrots have language centers functionally analogous to Broca's and Wernicke's areas (called RA and HVC, respectively; Vu, Mazurek, & Kuo, 1994). Finally, birds also have a dominant side of the brain for controlling song: dominant-side lesions to HVC in both canary and zebra finch brains severely disrupted their songs (Nottebohm, 1977; H. Williams, Crane, Hale, Esposito, & Nottebohm, 1992).

? Do other animals share our brain structures for language?

Many researchers consider hand and face gestures to be more analogous to human speech than animal vocalizations are. They think that our ancestors communicated this way, aided in forming this simple but effective prelanguage by emerging language structures (Holden, 2004a; MacNeilage, 1998). Chimpanzees, our best living window into that ancestral past, communicate primarily through hand and face gestures (Figure 9.28), and one-third of the hand gestures used by chimpanzees in the wild are like those used by humans, such as beckoning to an individual or waving an individual away (A. I. Roberts, Vick, Roberts, Buchanan-Smith, & Zuberbühler, 2012). These researchers also believe that the ability to imitate gestures was critical to the development of language in humans; in fact, research indicates that children initially learn speech not by imitating sounds but by imitating the actions of the mouth (Goodell & Studdert-Kennedy, 1993), and the amount of gesturing at 14 months predicts vocabulary size at 54 months (Rowe & Goldin-Meadow, 2009). Now language theorists think they have identified the mechanism for the imitative development of language in mirror neurons, which you learned about in Chapter 8.

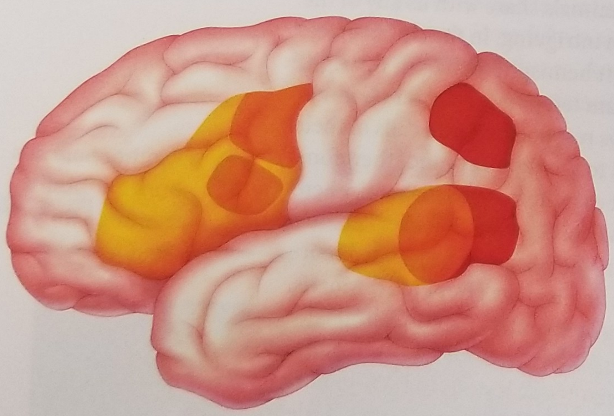
Mirror neurons were first discovered in the area of the monkey brain that corresponds to Broca's area; they respond not only to monkeys' hand movements but also to communicative mouth gestures such as

FIGURE 9.28 A Chimpanzee Communicating With Face and Hand Gestures.

Source: Karl Ammann/The Image Bank/Getty.

FIGURE 9.29 Overlap Between Language Areas and Areas Involved in Imitation.

Yellow indicates Broca's and Wernicke's areas and nearby areas that are active during imitation of acts by others. The overlapping brown areas are also active, and red indicates additional areas involved in imitation.



Source: Image provided courtesy of Dr. Marco Iacoboni. Adapted from "The Origin of Speech," by C. Holden, 2004, *Science*, 303, p. 1318.

lip smacking (Ferrari, Gallese, Rizzolatti, & Fogassi, 2003). In humans, they are in Broca's area and Wernicke's area and in the parietal lobe (Grèzes, Armony, Rowe, & Passingham, 2003; Holden, 2004a). Human mirror neurons are most active during imitation of another's movement (Iacoboni et al., 1999), which has encouraged the belief that they figure prominently in imitative ability and, thus, in the evolution of language (Figure 9.29). However, the fact that we share mirror neurons with monkeys and chimpanzees does not imply that monkeys and chimpanzees also share our language abilities. In fact, the evolutionary clues we do have suggest that language developed well after the split that led to humans and chimpanzees (Holden, 2004a). In addition, the involvement of songbird HVC neurons in both the perception and the production of song is highly analogous to mirror neurons in human language centers (Prather et al., 2008), suggesting that any species with mirror neurons may be capable of eventually evolving language. Whatever brain foundations of language we share with other animals required extensive refinement, such as expansion of the brain, including the language areas; migration of the larynx lower in the throat, which increased vocalization range; and the development of imitative ability, which is poor in nonhuman primates (Holden, 2004a).

Suggesting that language is a product of evolution means, of course, that genes are involved. *KIAA0319*, one of the genes contributing to dyslexia, also plays a role in the development of speech and language (M. L. Rice, Smith, & Gayán, 2009), and *CNTNAP2* and *ATP2C2* have been implicated in language impairment (Newbury, Fisher, & Monaco, 2010; Vernes et al., 2008). *ROBO1*, a gene that controls axon guidance in fetal speech and hearing areas (C. Johnson, Drgon, McMahon, & Uhl, 2009), has been implicated in a particularly severe type of dyslexia (Hannula-Jouppi et al., 2005) and is also found in avian brain areas involved in song learning (R. Wang et al., 2015). But the most researched and best understood language gene is *FOXP2*. A mutation of this gene results in reduced gray matter in Broca's area, along with articulation difficulties, problems identifying basic speech sounds, grammatical difficulty, and trouble understanding sentences (C. S. L. Lai, Fisher, Hurst, Vargha-Khadem, & Monaco, 2001; Pinker, 2001; Vargha-Khadem, Gadian, Copp, & Mishkin, 2005). We also share this gene with chimpanzees, but the human version differs in two apparently very important amino acids. The human version has been found in Neanderthal remains (J. Krause et al., 2007), and other fossil and archaeological evidence suggests to some researchers that the Neanderthals had the capacity for language. According to the researchers, the Neanderthals' increased nerve supply (assessed from the size of the bony pathways) enabled the voluntary control of the tongue and respiratory muscles necessary for speech; their auditory system specialized them for sensitivity in the speech range; and the spread of complex tool designs implied the imitative ability involved in learning speech (Dediu & Levinson, 2013). In a recent study, mice genetically altered to carry a human form of *FOXP2* enhanced their ability to turn thoughts into actions through increased dopamine activity in the striatum (an area involved in fine movements and memory; Schreiweis et al., 2014). Although the evidence is circumstantial and the interpretation subjective, it does appear that modern language has roots in the far distant past. However, not all the innovation has been in the human ancestral line, as the accompanying In the News feature reveals.

IN THE NEWS

LANGUAGE DIALECTS: YOU ARE FROM WHAT YOU SAY

Did you know your state (or country) of origin could be deduced by the words you say? While someone from the United Kingdom might say "knackered" when tired, and folks from Australia call a charcoal grill a "barbie," there is evidence of strong regional dialects in the United States itself. A book by a statistician, Joshua Katz, of North Carolina State University, demonstrates that there are some remarkably precise and predictable dialect boundaries in American English (Katz, 2016).

Do you call a carbonated beverage "pop," "soda," or "coke"? The "pop" crowd tends to be in the northern United States. The "soda" group includes the desert Southwest, the Northeast, and for some reason the area around St. Louis. The "coke" bunch is in the South, east of New Mexico. Do you call the thing you drink water out of in school a "bubbler"? You're from Wisconsin. Do you call something diagonally across an intersection "catty-corner," or do you say "kitty-corner"? That separates those who grew up in the South (catty) from those who grew up in the North and West (kitty). Sometimes a particular word can originate from a very small area. In Putnam and Westchester counties in New York, where Gerald grew up, there was a rather unique name for a sandwich with meats, vegetables, and cheese: They call it a "wedge" because of the slice taken out of the bread roll. The best meatball wedge in the area came from Rodak's restaurant in Mahopac, New York. Good stuff. Gerald is from New York, so he enjoys bottles of "soda," refers to a group of people as "you guys," and wears "sneakers." Bob, on the other hand, grew up in Texas, so he calls these things "coke," "y'all," and "tennis shoes." If you want to learn about geographical language oddities (like the Deep South term "the devil beating his wife" for when it rains when the sun is shining) and other dialectical differences, be sure to read Katz's book, *Speaking American* (2016).

So where do we get these localized differences in language, seeing that we all learn the same basic language rules and vocabulary in school? We learn these differences during the sensitive period of our language development, when a group of people decide to call something a unique term, and it passes from person to person through cultural learning until most of the people in that area use the same term. Once learned, we carry these regional differences with us for the rest of our lives, which serves as a reminder of where we began our journeys. They indicate the background we've each had and the experiences we went through, and they provide clues to how little we seem to travel from our birth areas.

CONCEPT CHECK

Take a Minute to Check Your Knowledge and Understanding

- In what ways is the Wernicke-Geschwind model correct? In what ways is it incorrect?
- What are the different roles of the left and right hemispheres in language (in most people)? (See Chapter 8 for part of the answer.)
- What clues are there in dialects for the movements of people?

In Perspective

Our guess is that at the beginning of this chapter you would have said that vision is the most important sense. Perhaps now you can appreciate why Helen Keller thought her deafness was a greater handicap than her blindness. Hearing alerts us to danger, brings us music, and provides for the social interactions that bind humans together. Small wonder that during evolution, the body invested such resources in the intricate mechanisms of hearing.