

Language

Language Has Many Functional Levels: Phonemes, Morphemes, Words, and Sentences

Language Acquisition in Children Follows a Universal Pattern

The "Universalist" Infant Becomes Linguistically Specialized by Age 1 Year

Language Uses the Visual System

Prosodic Cues Assist Learning of Words and Sentences

Infants Use Transitional Probabilities to Identify Words in Continuous Speech

There Is a Critical Period for Language Learning

"Motherese" Enhances Language Learning

Several Cortical Regions Are Involved in Language Processing

Language Circuits in the Brain Were First Identified in Studies of Aphasia

The Left Hemisphere Is Specialized for Phonetic, Word, and Sentence Processing

Prosody Engages Both Right and Left Hemispheres Depending on the Information Conveyed

Language Processing in Bilinguals Depends on Age of Acquisition and Language Use

The Model for the Neural Basis of Language Is Changing

Brain Injuries Responsible for the Aphasias Provide Important Insights into Language Processing

Broca Aphasia Results from a Large Lesion in the Left Frontal Lobe

Wernicke Aphasia Results from Damage to Left Posterior Temporal Lobe Structures

Conduction Aphasia Results from Damage to a Specific Sector of Posterior Language Areas

Global Aphasia Results from Widespread Damage to Several Language Centers

Transcortical Aphasias Result from Damage to Areas Near Broca's and Wernicke's Areas

The Classical Aphasias Have Not Implicated All Brain Areas Important for Language

An Overall View

LANGUAGE IS UNIQUELY HUMAN and arguably our greatest skill and our highest achievement. Despite its complexity, all typically developing children master it by the age of three. What causes this universal developmental phenomenon, and why are children so much better at acquiring a new language than adults? Once language is mastered, what brain systems are involved in language processing, and how does brain damage produce the various disorders of language known as the aphasias?

For centuries these questions about language and the brain have prompted vigorous debate among theorists. In the last decade, however, an explosion of information regarding language has taken us beyond the nature-nurture debates and beyond the standard view of specialized brain areas responsible for language. Two factors are largely responsible for this change.

First, functional brain imaging techniques such as positron emission tomography (PET), functional magnetic resonance imaging (fMRI), electroencephalography, and magnetoencephalography have allowed us to examine activation patterns in the brain while the subject carries out language tasks—naming objects

or actions, listening to sounds or words, or detecting grammatical anomalies. The results of these studies reveal a far more complex picture than the one first conceived of by Carl Wernicke in 1874, a picture in which multiple and relatively segregated brain systems cooperate functionally in language processing.

Second, behavioral and brain studies of language acquisition show that infants learn language in ways that had not been envisioned. Well before children produce their first words, they learn the sound patterns underlying the phonetic units, words, and phrase structure of the language they hear. Listening to language alters the infant brain early in development, and early language learning affects the brain for life. These new findings have led to a new view of language that encompasses its development, mature state, and dissolution in aphasia.

Humans are not the only species to communicate. Passerine birds attract mates with songs, bees code the distance and direction to honey by dancing, and monkeys signal a desire for sexual contact or fear at the approach of an enemy with coos and grunts. With language we accomplish all of the above and more. We use language to provide information and express our emotions, to comment on the past and future, and create fiction and poetry. Using sounds that have only an arbitrary association with the meanings they convey, we talk about anything and everything. No animal has a communication system that parallels human language either in form or in function. Language is the defining characteristic of humans, and living without it creates a totally different world, as patients with aphasia following a stroke experience so heartbreakingly.

Language Has Many Functional Levels: Phonemes, Morphemes, Words, and Sentences

What distinguishes language from other forms of communication? The key feature is a finite set of sounds that can be combined with infinite possibilities. This set of sounds or phonemes is used to create semantic units called morphemes. Each language has a distinctive set of phonemes and rules for combining them into morphemes and words. Words can be combined according to the rules of syntax into an infinite number of sentences.

Understanding language presents an interesting set of puzzles, one that even supercomputers have thus far not mastered. Computers even have difficulty with phonetic discrimination. For example, in English the sounds /r/ and /l/ differentiate the words *rock* and *lock*. In Japanese, however, this sound change does not

alter the meaning of a word as the /r/ and /l/ sounds are used interchangeably. Similarly, Spanish speakers distinguish between the words *pano* and *bano*, whereas English speakers treat the /p/ and /b/ sounds at the beginning of these words as the same sounds. Given that many languages use identical sounds, but group them differently, children must discover how sounds are grouped to make meaningful differences in their language.

Phonetic units are sub-phonemic. As we have illustrated above with /r/ and /l/, they are both phonetic units but their phonemic status differs in English and Japanese. In English, the two are phonemically distinct, meaning that they change the meaning of a word. However, in Japanese /r/ and /l/ belong to the same phonemic category and are not distinct. Phonetic units are distinguished by subtle variations in vibrations of the vocal tract called *formant frequencies* (Figure 60–1). The patterns and timing of formant frequencies distinguish words that differ in only one phonetic unit, such as the words *pat* and *bat*. In normal speech, formant changes occur very rapidly, on the order of milliseconds. The auditory system has to track these rapid changes to distinguish semantically different sounds and understand speech. Identifying words in written language is easy because there are spaces between words. However, in speech there are no acoustic breaks between words. Thus speech requires a process that can detect words on the basis of something other than sounds bracketed by silence. Computers have a great deal of trouble recognizing words in the normal flow of speech.

Phonotactic rules specify how phonemes can be combined to form words. Both English and Polish use the phonemes /z/ and /b/, for example, but the combination *zb* is not allowed in English, whereas in Polish it is common (as in the name *Zbigniew*).

Morphemes are the smallest meaningful units of a language, best illustrated by prefixes and suffixes. In English, for example, the prefix *un* (meaning *not*) can be added to many adjectives to convey the opposite meaning (eg, *unimportant*). Suffixes often signal the tense or number of a word. For example, to pluralize in English we add *s* or *es* (*pot* becomes *pots*, *bug* becomes *bugs*, or *box* becomes *boxes*). To change the tense of a regular verb we add an ending to the word (eg, *play* can become *plays*, *playing*, and *played*). Irregular verbs do not follow the rule (eg, *go* becomes *went* rather than *goed*, and *break* becomes *broke* rather than *breaked*). Every language has a different set of rules for altering the tense and number of a word.

Finally, to create language, words have to be strung together. *Syntax* specifies word and phrase order for

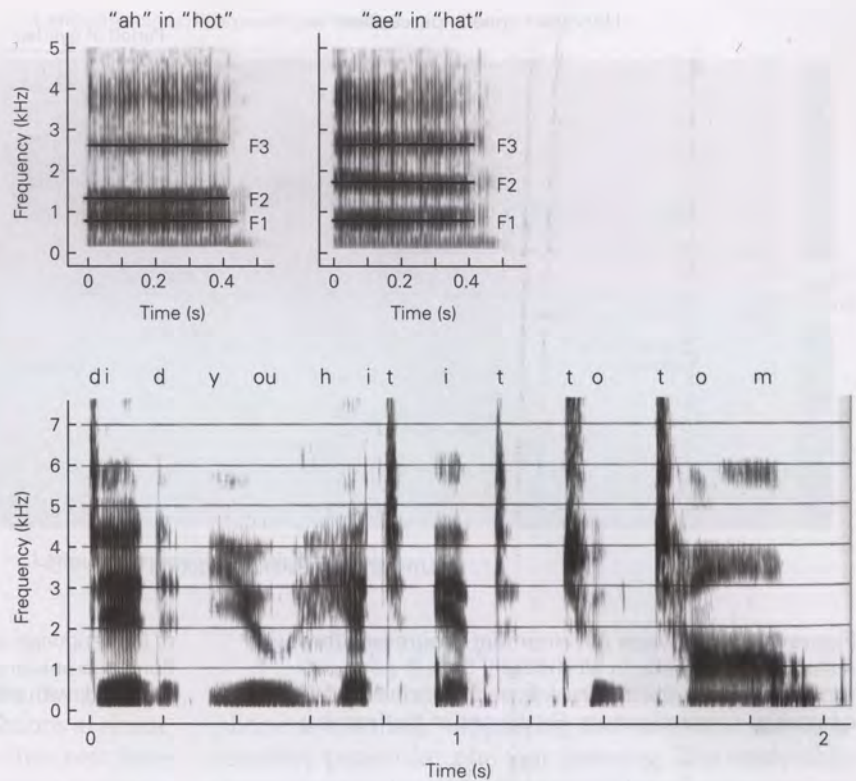


Figure 60-1 Formant frequencies. Formants, shown here as a function of time in a spectrographic analysis of speech, are systematic variations in the concentration of energy at various frequencies, and represent resonances of the vocal tract. The formant patterns for two simple vowels ("ah" and "ae") spoken in isolation are distinguished by differences in formant 2 (F2). Formant patterns for the sentence "Did you hit it to Tom?" spoken slowly and clearly illustrate the rapid changes that underlie normal speech. (Adapted, with permission, from Kuhl 2000.)

a given language. In English, for example, sentences typically conform to a subject–verb–object order (eg, *He eats cake*), whereas in Japanese, it is typically subject–object–verb (eg, *Kare wa keeki o tabemasu*, literally, *He cake eats*). Languages have systematic differences in the order of larger constituents (noun phrases and verb phrases) of a sentence, and in the order of words within constituents, as illustrated by the difference between English and French noun phrases. In English adjectives precede the noun (eg, *a very intelligent man*), whereas in French most follow the noun (eg, *un homme très intelligent*).

Language Acquisition in Children Follows a Universal Pattern

Regardless of culture, all children initially exhibit universal patterns of speech perception and production that do not depend on the specific language children hear (Figure 60-2). By the end of the first year infants have learned through exposure to a specific language which phonetic units convey meaning in that language and recognize likely words, even though they do not yet understand those words. By 12 months of age

infants understand approximately 50 words and have begun to produce speech that resembles the native language. By the age of 3 years children know approximately 1,000 words (by adulthood 70,000), create long adult-like sentences, and can carry on a conversation.

In the last half of the 20th century debate on the nature and acquisition of language was ignited by a highly publicized exchange between a strong learning theorist and a strong nativist. In 1957 the behavioral psychologist B. F. Skinner proposed that language was acquired through learning. In his book *Verbal Behavior* Skinner argued that language, like all animal behavior, was a learned behavior that developed in children as a function of external reinforcement and careful parental shaping. By Skinner's account infants learn language as a rat learns to press a bar—through monitoring and management of reward contingencies. The nativist Noam Chomsky, writing a review of *Verbal Behavior*, took a very different position. Chomsky argued that traditional reinforcement learning has little to do with humans' abilities to acquire language. Instead, every individual has an innate "language faculty" that includes a universal grammar and a universal phonetics; exposure to a specific language triggers a "selection" process for one language.

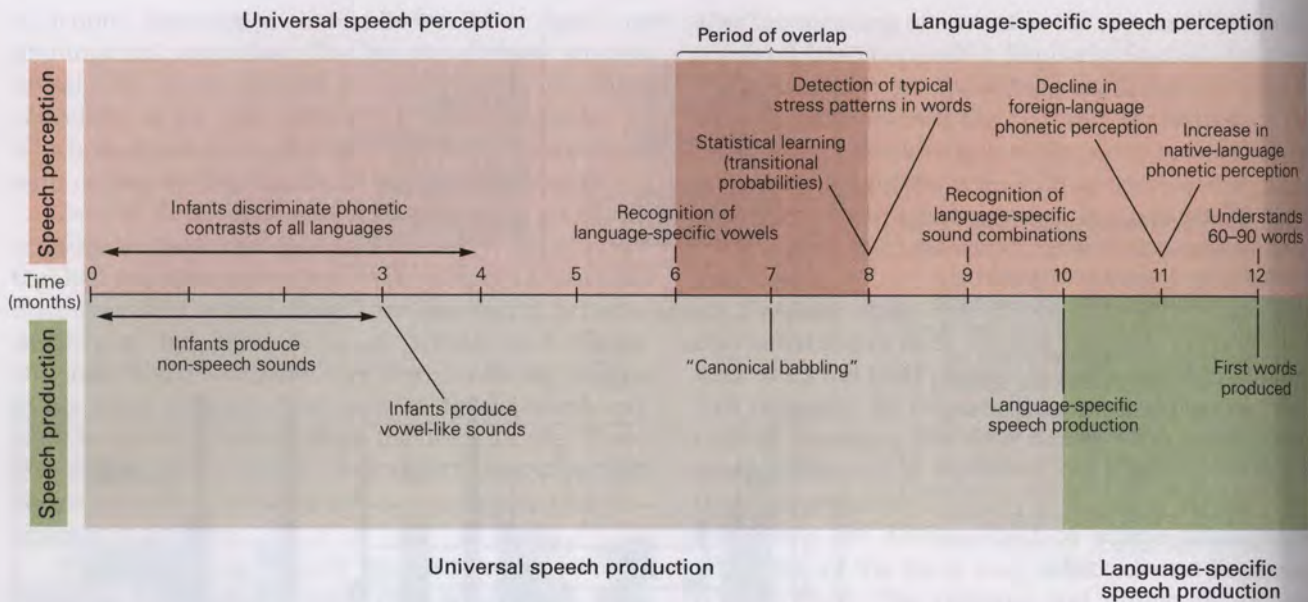


Figure 60-2 Language development progresses through a standard sequence in all children. Speech perception and production in children in various cultures initially follow a language-universal pattern. By the end of the first year

of life, language-specific patterns emerge. Speech perception becomes language-specific before speech production. (Adapted, with permission, from Doupe and Kuhl 1999.)

More recent studies of language acquisition in infants and children have clearly demonstrated that the kind of learning going on in infancy does not resemble that described by Skinner with its reliance on external shaping and reinforcement. However, a nativist account such as Chomsky's, in which the language the infant hears triggers a choice among innate options, also does not capture the process.

The "Universalist" Infant Becomes Linguistically Specialized by Age 1 Year

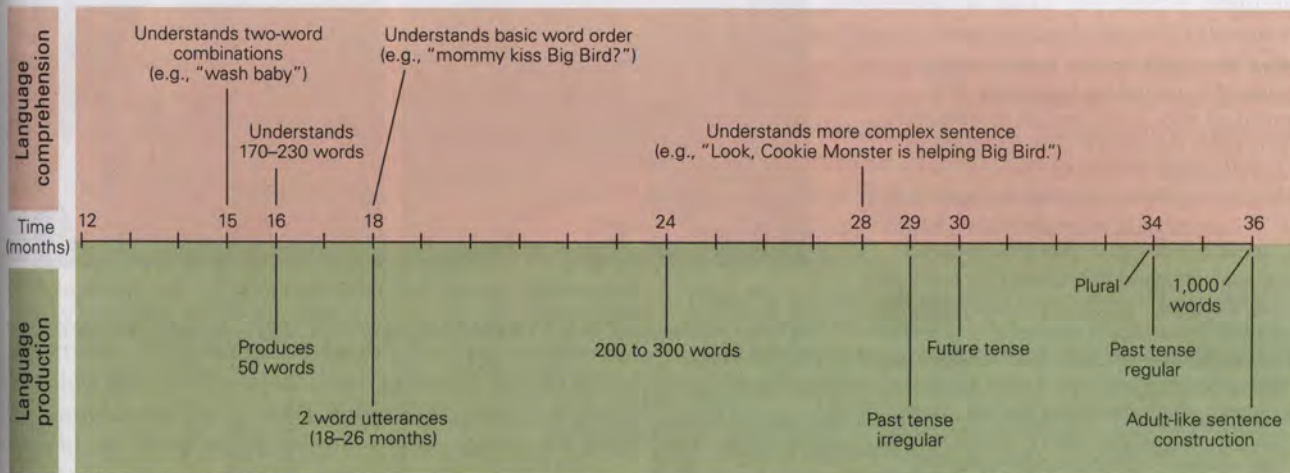
In the early 1970s psychologist Peter Eimas showed that infants were especially good at hearing the acoustic changes that distinguish phonetic units in the world's languages. He showed that infants could discern slight acoustic changes at the boundaries between phonetic categories, and that they could do this for phonetic units in languages they had never experienced. The phenomenon is called *categorical perception*; adults have this ability only for phonetic units in languages in which they are fluent. Japanese people, for example, find it very difficult to hear the distinction between the American English /r/ and /l/ sounds. Both are perceived as Japanese /r/, and, as we have seen, Japanese speakers use the two sounds interchangeably when producing words.

Categorical perception was originally thought to occur only in humans, but in 1975 cognitive neuroscientist Patricia Kuhl showed that it exists in nonhuman mammals such as chinchillas and monkeys. Since then many studies have confirmed this result (as well as species differences). The studies suggest that the evolution of phonetic units was strongly influenced by preexisting auditory structures and capacities. Infants' ability to hear all possible differences in speech prepares them to learn any language; at birth they are linguistic "universalists."

Right before the onset of first words, infants' ability to discriminate nonnative phonetic units rapidly declines. By the end of the first year, infants fail to discriminate phonetic changes that they successfully recognized 6 months earlier. At the same time, infants become significantly more adept at hearing native-language phonetic distinctions. For example, when American and Japanese infants were tested between 6 and 12 months of age on the discrimination of the American English /r/ and /l/, American infants improved significantly between 8 and 10 months, whereas Japanese infants declined, suggesting that this is a sensitive period for phonetic learning.

Speech production develops simultaneously with speech perception (Figure 60-2). All infants, regardless of culture, produce sounds that are universal. Infants

Language-specific speech perception



Language-specific speech production

"coo" with vowel-like sounds at 3 months of age, and "babble" using consonant-vowel combinations at about 7 months of age. Toward the end of the first year language-specific patterns of speech production begin to emerge in infants' spontaneous utterances. As children approach the age of 2 years, they begin to mimic the sound patterns of their native language. Chinese toddlers' utterances reflect the pitch, rhythm, and phonetic structure of Mandarin, and the utterances of British toddlers sound distinctly British. Infants develop an ability to imitate the sounds they hear others produce as early as 20 weeks of age. Very early in development infants begin to master the subtle motor patterns required to produce their "mother tongue." Speech-motor patterns acquired in the earliest stages of language learning persist throughout life and influence the sounds, tempo, and rhythm of a second language learned later.

The second half of the first year appears to be a sensitive period for speech learning. If infants are exposed to a new language at this time, do they learn? Kuhl exposed American infants to Mandarin Chinese in the laboratory between 9 and 10 months of age and found that the infants learned if exposure occurred through interaction with a human being; infants exposed to the exact same material through television or audiotape with no live human interaction do not learn (Figure 60-3). When tested, the performance of the live-exposure group was statistically indistinguishable from that of infants raised in Taiwan who had listened to Mandarin for 10 months (Figure 60-3). These results established that at 9 months of age the

right kind of exposure to a foreign language permits phonetic learning, supporting the view that this is a sensitive period for phonetic learning. The study also demonstrated, however, that social interaction appears to play an essential role in learning.

What causes the change in infants' perception between 6 and 12 months of age? Studies of infants suggest that early exposure to speech induces an implicit learning process that reduces the infant's initial ability to hear distinctions between foreign-language sounds. At 6 months of age infants begin to organize speech sounds into categories based on *phonetic prototypes*, ie, the most frequently occurring phonetic units in their language. Six-month-old infants in the United States and Sweden were tested with prototypical English and Swedish vowels to examine whether infants discriminated acoustic variations in the vowels, like those that occur when different talkers produce them. By 6 months of age the American and Swedish infants ignored acoustic variations around native-language prototypes. This "category perception" did not occur with nonnative prototypes. This explains why 11-month-old Japanese infants fail to discriminate English /r/ and /l/ after experience with Japanese. Brain imaging and behavioral tests on infants confirm this change between 7 and 11 months of age.

Language Uses the Visual System

Language is typically communicated through an auditory-vocal channel. However, deaf speakers communicate through a visual-manual channel. Natural

Figure 60-3 Infants can learn the phonemes of a nonnative language at 9 months of age. Three groups of American infants were exposed for the first time to a new language (Mandarin Chinese) in 12 25-minute sessions between the ages of 9 and 10.5 months. One group interacted with live native speakers of Mandarin; a second group was exposed to the identical material through television; and a third group heard tape recordings only. A control group had similar language sessions but heard only English. Performance on discrimination of Mandarin phonemes was tested in all groups after exposure (11 months). Only infants exposed to live Mandarin speakers discriminated the Mandarin phonemes. Infants exposed through TV or tapes showed no learning, and were indistinguishable from the controls (who heard only English). The performance of American infants exposed to live Mandarin speakers was equivalent to monolingual Taiwanese infants of the same age who had experienced Mandarin from birth. (Reproduced, with permission, from Kuhl, Tsao, and Liu 2003.)

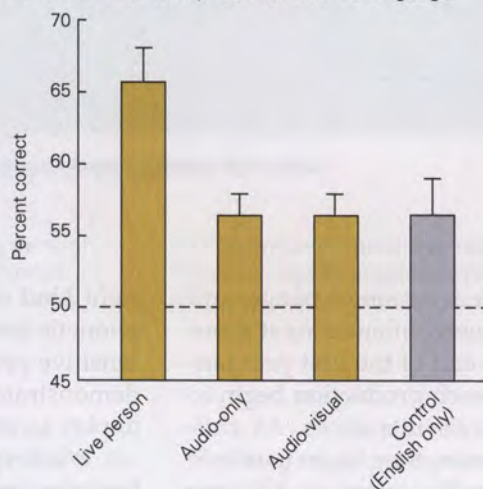
Live exposure



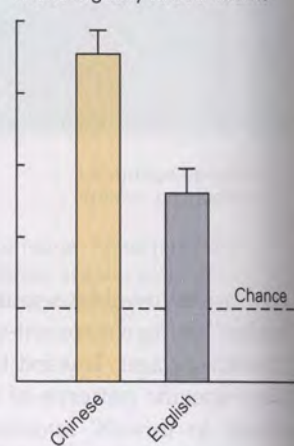
Audiovisual exposure



American infants exposed to Chinese language



Monolingually raised infants



signed languages, such as American Sign Language (Ameslan or ASL), are those invented by the deaf and vary across countries. Deaf infants “babble” with their hands at approximately the same time in development as hearing infants babble orally. Other developmental milestones, such as first words and two-word combinations, also occur on the developmental timetable of hearing infants.

Additional studies indicate that visual information of another kind, the face of the talker, is not only very helpful for communication but also affects the everyday perception of speech. We all experience the benefits of “lip-reading” at noisy parties—watching speakers’ mouth movements helps us understand speech in a noisy environment. The most compelling laboratory demonstration that vision plays a role in everyday speech perception is the illusion that results when discrepant speech information is sent to the visual and auditory modalities. When subjects hear the sound /ba/ while watching a person pronounce “ga,” they report hearing an intermediate articulation /da/. Such demonstrations support the idea that

speech categories are defined both auditorily and visually, and that perception is governed by both sight and sound.

Prosodic Cues Assist Learning of Words and Sentences

Long before infants recognize that things and events in the world have names, they memorize the global sound patterns typical in their language. Infants use the *prosodic* cues in speech—the pitch, duration, and loudness changes—that occur in words to learn these patterns. In English, for example, a strong/weak pattern of stress is typical—as in the words “BABy,” “MOMmy,” “TAble,” and “BASEball”—whereas in other languages a weak/strong pattern predominates. Six and 9-month-old infants given a listening choice between words in English or Dutch show a listening preference for native-language words at the age of 9 months (but not at six months).

Prosodic cues convey both linguistic information (differences in intonation and tone in languages

such as Chinese) and paralinguistic information, such as the emotional state of the speaker. Even in utero infants learn by listening to the prosody of speech produced by their mothers. Certain sounds are transmitted through bone conduction to the womb; these are typically intense (above 80 dB), low-frequency sounds (particularly below 300 Hz, but as high as 1,000 Hz with some attenuation). Thus the prosodic patterns of speech, including voice pitch and the stress and intonation patterns characteristic of a particular language and speaker, are transmitted to the fetus, while the sound patterns that convey phonetic units and words are greatly attenuated. At birth infants demonstrate learning that depends on this prosodic information by showing listening preferences for (a) the language spoken by their mothers during pregnancy, (b) their mother's voice over that of another female, and (c) stories with a distinct tempo and rhythm read by the mother during the last 10 weeks of pregnancy.

Infants Use Transitional Probabilities to Identify Words in Continuous Speech

Seven- to 8-month-old infants recognize words using the probability that one syllable will follow another. The transitional probabilities between syllables in a word are high because the sequential order remains constant. In the word *potato*, for example, the syllable "ta" always follows the syllable "po" (probability of 1.0). Transitional probabilities between words, as between "hot" and "po" in the string "hot potato," are much lower.

Jenny Saffran showed that infants treat phonetic units and syllables with high transitional probabilities as word-like units. In one experiment infants heard 2-minute strings of pseudo-words, such as *tibudo*, *pabiku*, *golatu*, and *daropi*, without any acoustic breaks between them. They were then tested for recognition of these pseudo-words as well as new ones formed by combining the last syllable of one word with the two initial syllables of another word (such as *tudaro* formed from *golatu* and *daropi*). Infants recognized the original pseudo-words, indicating that they use the transitional probabilities to identify words.

These forms of learning clearly do not involve Skinnerian reinforcement. Caretakers do not manage the contingencies and gradually, through reinforcement strategies, shape the statistical analyses performed by infants. Conversely, language learning by infants also does not appear to reflect a process in which innately provided options are chosen based on language experience. Rather, infants learn language through detailed and sophisticated analysis of the language they hear, an analysis that reveals to them patterns of variation

in natural language. The learning of these patterns in turn alters perception to favor the native language. What infants learn is constrained by the architecture of the brain, and language evolved to capitalize on infant learning. This mirrors the argument that the development of phonetic units was significantly influenced by the features of mammalian hearing, ensuring that infants would find it easy to discriminate phonemes, the fundamental units of meaning in language.

There Is a Critical Period for Language Learning

Children learn language more naturally and efficiently than adults, a paradox given that the cognitive skills of adults are superior. Why should this be the case?

Many consider language acquisition to be an example of a skill that is learned best during a *critical period* in development. Eric Lenneburg proposed that maturational factors at puberty caused a change in the neural mechanisms that control language acquisition. Evidence supporting this view comes from classic studies of Chinese and Korean immigrants to the United States who were immersed in English at ages ranging from 3 to 39 years. When asked to identify errors in sentences containing grammatical mistakes, an easy task for native speakers, second-language learners' performance declined with the age of arrival in the United States. A similar trend emerges when one compares individuals exposed to ASL from birth to those exposed between 5 and 12 years of age. Those exposed from birth were best at identifying errors in ASL, those exposed at age 5 were slightly poorer, and those exposed after the age of 12 years were substantially poorer.

What restricts our ability to learn a new language after puberty? Developmental studies suggest that prior learning plays a role. Learning a native language produces a *neural commitment* to detection of the acoustic patterns of that language, and this commitment interferes with later learning of a second language. Early exposure to language results in neural circuitry that is "tuned" to detect the phonetic units and prosodic patterns of that language. Neural commitment to native language enhances the ability to detect patterns based on those already learned (eg, phonetic learning supports word learning), but reduces the ability to detect patterns that do not conform. Learning the motor patterns required to speak a language also results in neural commitment. The motor patterns learned for one language are often incompatible with those required for pronunciation of the second language and thus can interfere with efforts to pronounce the second language without an accent.

Early in life two or more languages can be easily learned because interference effects are minimal until neural patterns are well established. We know little about how the brain handles the representation of two distinct languages when presented with both initially. The currently favored position is that experience, as well as maturation, are the major factors leading to the developmental critical period for language. Maturation can set the time when the window for learning “opens,” but experience can be primarily responsible for determining when the window “closes.” Both factors—a maturational development that enables learning and the neural commitment that results from learning—likely operate together to constrain learning a new language later in life.

We do not completely lose the ability later in life to learn a new language. Regardless of the age at which learning begins, second-language learning is improved by a training regime that mimics critical components of early learning—long periods of listening in a social context (immersion), the use of both auditory and visual information, and exposure to simplified and exaggerated speech resembling “motherese.”

“Motherese” Enhances Language Learning

Everyone agrees that when adults talk to their children they sound unusual. Discovered by linguists and anthropologists in the early 1960s as they listened to languages spoken around the world, “motherese” (or “parentese,” as fathers produce it as well) is a special speaking style used when addressing infants and young children. Motherese has a higher pitch, slower tempo, and exaggerated intonation contours, and is easily recognized.

Compared to adult-directed speech, the pitch of the voice is increased on average by an octave both in males and in females. Phonetic units are spoken more clearly and are acoustically exaggerated, thus increasing the acoustic separation of phonetic units. Adults speaking to infants exaggerate just those features of speech that are critical to their native language. Chinese mothers, for example, exaggerate the four tones in Mandarin that are critical to word meaning in Chinese. Evidence suggests that motherese does in fact assist infants’ discrimination of phonetic units.

Infants prefer listening to infant-directed rather than adult-directed speech when given a choice. When infants are allowed to activate recordings of infant-directed or adult-directed speech, by turning left or right, they will turn in whatever direction is required to turn on infant-directed speech.

Several Cortical Regions Are Involved in Language Processing

Language Circuits in the Brain Were First Identified in Studies of Aphasia

Details of the neural basis of language first became apparent in the study of acquired language disorders known as aphasias. Focal brain lesions brought about by cerebrovascular diseases (stroke), head injury, and degenerative diseases such as Alzheimer and Pick disease cause the aphasias. Because language is unique to humans, animal models of language cannot be developed, and the study of aphasia remains an important source of information for elucidating the neural underpinnings of language.

The neural basis of language processing was first outlined in studies of the aphasias in the second half of the 19th century in France by Pierre Paul Broca and in Germany by Karl Wernicke. Based on their work and that of others, Wernicke formulated a model of neural processing of language (see Chapter 1). Most elements of this early model have stood the test of time. Prominent among these is the notion that in most individuals language processing depends more on structures in the left hemisphere than on those of the right. The left cerebral hemisphere is dominant for language in a majority of right-handed individuals and in a smaller but significant majority of left-handed individuals. Regardless of handedness, in more than 95% of individuals the grammar, lexicon, phonemic assembly, and phonetic production of language depend on the left hemisphere. Languages that rely on visual-motor signs rather than on auditory speech—signed languages such as ASL—also depend on the left hemisphere.

The early study of aphasia also revealed that damage to two brain areas, known as Broca’s area in the left lateral frontal region and Wernicke’s area in the left posterior superior temporal lobe, was associated with distinct profiles of language disorder, respectively Broca aphasia and Wernicke aphasia.

The Left Hemisphere Is Specialized for Phonetic, Word, and Sentence Processing

Although the conclusion that “we speak with the left hemisphere” is incontrovertible, the origin of that functional separation of the hemispheres during development is unclear. Whether left hemisphere specialization for language derives from a general tendency for the left hemisphere to engage in analytic processing or is a specific linguistic specialization is

not known. Studies by neuroscientist Helen Neville have shown that the left hemisphere is activated not only by auditory stimuli but also by visual stimuli that have linguistic significance. Deaf individuals process visual information in the speech-processing regions of the left hemisphere. Such studies suggest that the speech-related regions of the left hemisphere are well suited to processing expression independent of the modality.

When in development does the left hemisphere become dominant in language processing? Evidence from a variety of sources suggests that left hemisphere specialization for language develops rapidly in infancy. We do not know if left hemisphere dominance for language is present at birth or whether experience with language is required to produce differentiation of the hemispheres; neuroimaging studies on this issue are in progress.

Prosody Engages Both Right and Left Hemispheres Depending on the Information Conveyed

Prosodic information can be linguistic, conveying semantic meaning as tones do in Mandarin Chinese or Thai, and also paralinguistic, expressing our attitudes and emotions. The pitch of the voice carries both kinds of information, and the brain's processing of each kind of information differs. Emotional changes in pitch engage the right hemisphere, primarily in right frontal and temporal regions. A different pattern of brain activity occurs when pitch is used to convey semantic information.

A number of neuroimaging studies have investigated the neural processing of semantic tone. In Thai speakers, for example, the left frontal lobe is consistently activated in response to changes in tone (Figure 60-4). In speakers of a non-tonal language, such as native speakers of American English, or speakers who use tone differently than do Thai speakers, such as Mandarin Chinese speakers, the Thai words do not activate these left hemisphere regions (Figure 60-4).

The fact that the left hemisphere plays the dominant role in phonemic and grammatical processing does not mean that the right hemisphere plays no role in language. Right hemisphere processing of emotional information helps convey a speaker's mood and intentions, and this helps interpret sentence meaning. Patients with right hemisphere lesions often produce speech with inappropriate stress, timing, and intonation, and their speech sounds emotionally flat; they also frequently fail to interpret the emotional cues in others' speech.

The right hemisphere also plays a role in discourse. Patients with damage in the right hemisphere have difficulty ordering sentences into a coherent narrative. They also have difficulty comprehending meaning when the full meaning depends on the relationships among sentences rather than on each sentence taken in isolation. For this reason these patients often fail to understand jokes, and this has an impact in their social lives.

Language Processing in Bilinguals Depends on Age of Acquisition and Language Use

How are multiple languages represented in the human brain? Modern neuroimaging techniques allow bilingual processing to be studied more directly and in greater detail than in earlier studies. They show that both the age at which a second language is acquired and the degree of proficiency in the second language affect how the brain processes multiple languages. In "late" bilinguals (those who learned a second language in adulthood) the second language and native language are processed in spatially separated areas in the language-sensitive left frontal region. In "early" bilinguals (those who acquired both languages as children) the two languages are processed in the same area.

The Model for the Neural Basis of Language Is Changing

On the basis of new observations and the contribution of Norman Geschwind in the 1960s, neurologists further developed Wernicke's model for the neural basis of language. In this revised model, which came to be known as the Wernicke-Geschwind model, Wernicke's area was presumed to analyze the acoustic signals making up words, while Broca's area organized the articulation of speech. The arcuate fasciculus was assumed to be a unidirectional pathway that helped speech production by bringing information from Wernicke's area to Broca's.

In the model both Wernicke's and Broca's areas interact with association areas. Acoustic cues contained in a spoken word are processed by the auditory pathways and reach Wernicke's area, where the meaning of a word is elaborated and then conveyed to higher brain structures, for example in sectors of the inferior parietal cortex. Eventually such patterns are converted into acoustic patterns and transferred by the arcuate fasciculus into Broca's area and turned into vocalizations.

In this model the ability to read and write also depends on Wernicke's and Broca's areas. In the case of reading, Wernicke's area receives signals from areas of visual cortex on the left and activates the corresponding auditory patterns. In the case of writing, auditory activity that represents these patterns is converted into motor outputs in the premotor region (Exner's area) just above Broca's area.

For several years the Wernicke-Gerschwind model provided a useful framework for the investigation of the neural basis of language processes. It also formed the basis for a practical classification of the aphasias that clinical neurologists still use today (Table 60-1). However, details of the model were called into question by the advent of structural magnetic resonance imaging, and the development of psycholinguistics.

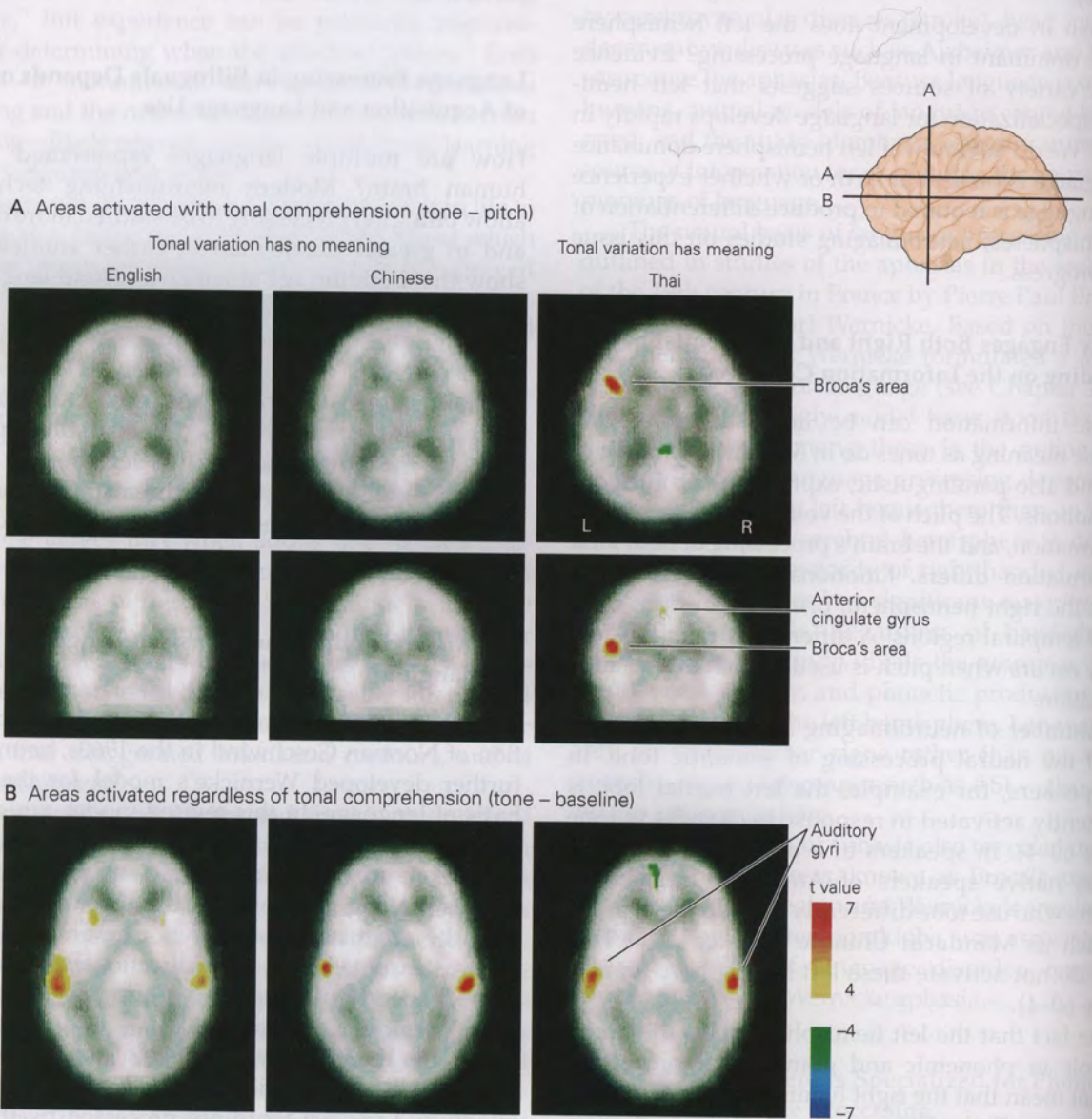


Figure 60-4 Brain activity patterns differ in speakers of tonal and nontonal languages. Positron emission tomography (PET) images show that cerebral blood flow (CBF) differs in Thai, Mandarin Chinese, and American English subjects listening to Thai variations in tone. (Reproduced, with permission, from Gandour et al. 2000.)

A. Only Thai listeners have CBF increases in the left Broca's area and also in the anterior cingulate gyrus. "Tone – pitch" means that the tone task and the pitch task are being compared

using the standard subtraction technique (tone activation minus pitch activation). There is relatively more activation in the tone task compared to the pitch task (the pitch task was used as the reference baseline).

B. The "tone – baseline" condition compares the tone task with a "resting" condition, which is also standard procedure in these studies. All three groups show similar CBF increases in the auditory gyri.

Table 60-1 Differential Diagnosis of the Main Types of Aphasia

Type of aphasia	Speech	Comprehension	Capacity for repetition	Other signs	Region affected
Broca	Nonfluent, effortful	Largely preserved for single words and grammatically simple sentences	Impaired	Right hemiparesis (arm > leg); patient aware of defect and can be depressed	Left posterior frontal cortex and underlying structures
Wernicke	Fluent, abundant, well articulated, melodic	Impaired	Impaired	No motor signs; patient can be anxious, agitated, euphoric, or paranoid	Left posterior superior and middle temporal cortex
Conduction	Fluent with some articulatory defects	Intact or largely preserved	Impaired	Often none; patient can have cortical sensory loss or weakness in right arm	Left superior temporal and supramarginal gyri
Global	Scant, nonfluent	Impaired	Impaired	Right hemiplegia	Massive left perisylvian lesion
Transcortical motor	Nonfluent, explosive	Intact or largely preserved	Intact or largely preserved	Sometimes right-sided weakness	Anterior or superior to Broca's area
Transcortical sensory	Fluent, scant	Impaired	Intact or largely preserved	No motor signs	Posterior or inferior to Wernicke's area

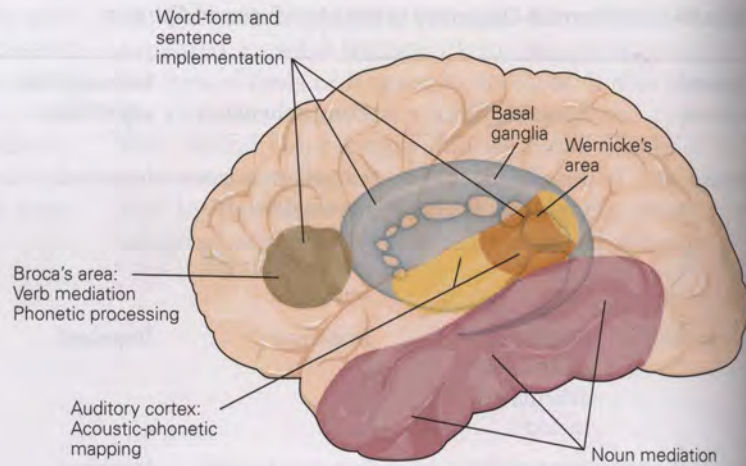
Functional imaging techniques and the direct recording of electrical potentials from the exposed cerebral cortex of patients undergoing surgery for epilepsy opened the possibility for conducting studies in normal individuals engaged in language tasks, and the results of such studies led to revisions of the model.

Together the new approaches have contributed to a better definition of the neural systems responsible for language. The roles of Wernicke's and Broca's areas have expanded, and the arcuate fasciculus is now known to be a bidirectional tract that interconnects larger areas of sensory cortex with prefrontal and premotor areas. Just as importantly, additional areas of the left hemisphere have been found to be involved in language processing. These new areas are located in association areas of the left frontal, temporal, and parietal regions, which appear to provide connections between the processing of concepts and words. Other areas in prefrontal and cingulate areas are thought to exert executive control and mediate working-memory and attentional processes. An additional locus of speech production has been identified in

the left insular region. In brief, in the revised version of the model the processing of language requires a far larger network of brain areas than was contemplated earlier.

As suggested by Hanna and Antonio Damasio, the new evidence indicates that three large systems interact to connect language reception and production with conceptual knowledge. Broca's and Wernicke's areas, selected sectors of insular cortex, and the basal ganglia form one system, a language *implementation system*. This system analyzes incoming auditory signals so as to activate conceptual knowledge and also supports phonemic and grammatical construction and controls speech production. It is anatomically surrounded by a second system, a *mediational system*, made up of numerous separate regions in the temporal, parietal, and frontal association areas. These regions act as brokers between the implementation system and a third system, a *conceptual system*, a collection of regions distributed throughout the association areas. In sum, a picture is emerging of a more complex neural network specialized in language processing (Figure 60-5).

Figure 60-5 Language processing involves distributed neural networks. Imaging studies show that language processing involves a more complex and distributed network than previously thought. Particular brain areas are specialized for processing at the phonetic, word, or sentence level.



Brain Injuries Responsible for the Aphasias Provide Important Insights into Language Processing

Broca Aphasia Results from a Large Lesion in the Left Frontal Lobe

Broca aphasia is a disorder of speech production that includes impairments of grammatical processing. Patients have labored and slow speech, articulation is impaired, and the melodic intonation of normal speech is lacking (Table 60-2). Yet patients sometimes have considerable success at verbal communication even when they are difficult to understand because their selection of certain types of words, especially nouns, is often correct. By contrast, verbs as well as grammatical words such as prepositions and conjunctions are poorly selected or can be missing altogether. Another major sign of Broca aphasia is a defect in the ability to repeat complex sentences spoken by the examiner. In general, patients with Broca aphasia give the impression that they comprehend the words and sentences they hear, but suitable tests reveal that comprehension is incomplete.

Because most patients with Broca aphasia give the impression of understanding conversational speech, the condition was initially thought to be a deficit of production only. But Broca aphasics only comprehend sentences whose meaning can be derived from the meaning of the words used. They have difficulty comprehending sentences with meanings that depend mostly on grammar. Broca aphasics can understand *The apple that the girl ate was green* but have trouble understanding *The girl that the boy is chasing is tall*. This

is because the patients can understand the first sentence without recourse to grammatical rules—girls eat apples, but apples do not eat girls; apples can be green, but girls cannot. The patients have difficulty with the second sentence, however, because both girls and boys can be tall, and either can chase the other. To understand the second sentence it is necessary to analyze its grammatical structure, something that Broca aphasics have difficulty doing.

Broca aphasia results from damage to Broca's area (the inferior left frontal gyrus, which contains Brodmann's areas 44 and 45); surrounding frontal fields (the external aspect of Brodmann's area 6, and areas 8, 9, 10, and 46); the underlying white matter, insula, and basal ganglia (Figure 60-6); and a small portion of the anterior superior temporal gyrus. A small sector of the insula, an island of cortex buried deep inside the cerebral hemisphere, can also be included in the correlates of Broca's aphasia. This is because patients who have lesions in a small part of the left insula have difficulty pronouncing phonemes in their proper order. They usually produce combinations of sounds that are very close to the target word, suggesting that they have trouble coordinating the articulatory movements necessary for speech. They have no difficulty perceiving speech sounds or recognizing their own errors and no trouble in finding words.

The structures damaged in Broca aphasia are part of a neural network involved in both the assembly of phonemes into words and the assembly of words into sentences. The network is presumably specialized for relational aspects of language, which include the grammatical structure of sentences and the proper use of grammatical vocabulary and verbs. The other

Table 60-2 Examples of Spontaneous Speech Production and Repetition for the Primary Types

Type of aphasia	Spontaneous speech	Repetition
Broca	Stimulus (Western Aphasia Battery picnic picture): What do you see in this picture? "O, yea. Det's a boy an' a girl . . . an' . . . a . . . car . . . house . . . light po' (pole). Dog an' a . . . boat. 'N det's a . . . mm . . . a coffee, an' reading. Det's a mm . . . a . . . det's a boy . . . fishin.'" (Elapsed time: 1 min 30 s)	Stimulus: "The pastry cook was elated." "Elated."
Wernicke	"Ah, yes, it's, ah . . . several things. It's a girl . . . uncurl . . . on a boat. A dog . . . 'S is another dog . . . Uh-oh . . . long's . . . on a boat. The lady, it's a young lady. An' a man A They were eatin.' 'S be place there. This . . . a tree! A boat. No, this is a . . . It's a house. Over in here . . . a cake. An' it's, it's a lot of water. Ah, all right. I think I mentioned about that boat. I noticed a boat being there. I did mention that before . . . Several things down, different things down . . . a bat . . . a cake . . . you have a . . ." (Elapsed time: 1 min 20 s)	"/I/ . . . no . . . In a fog."
Conduction	"Kay. I see a guy readin' a book. See a women /ka . . . he . . . /pourin' drink or something.' An' they're sittin' under a tree. An' there's a . . . car behind that an' then there's a house behind th' car. An' on the other side, the guy's flyn' a /fait . . . fait/(kite) See a dog there an' a guy down on the bank. See a flag blowin' in the wind. Bunch of /hi . . . a . . . /trees in behind. An a sailboat on th' river, river . . . lake. 'N guess that's about all . . . 'Basket there." (Elapsed time: 1 min 5 s)	"The baker was . . . What was that last word?" ("Let me repeat it: The pastry cook was elated.") "The baker-er was / vaskerin/ . . . uh . . ."
Global	(Grunt)	(No response)

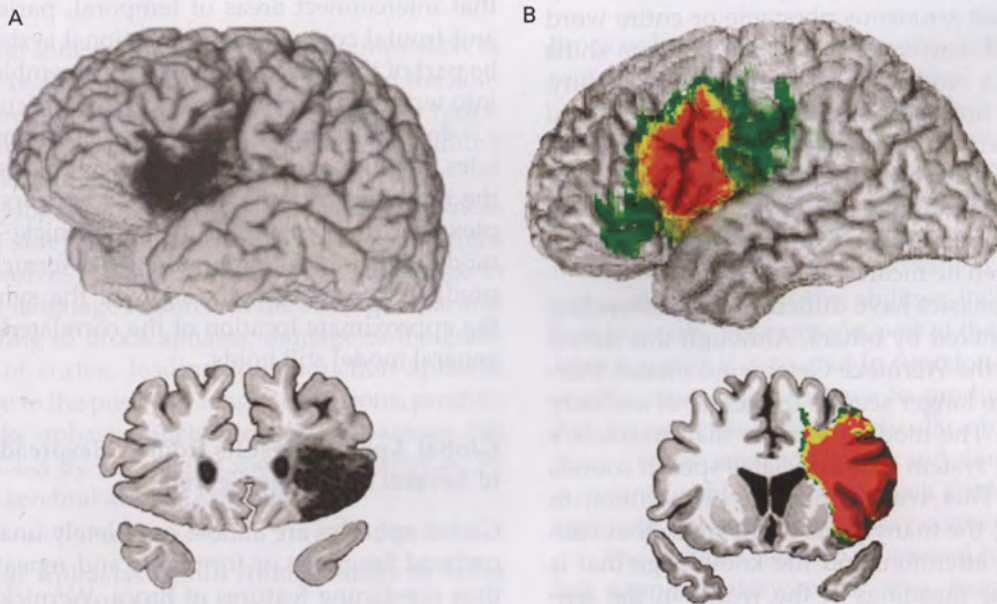


Figure 60-6 Sites of lesions in Broca aphasia. (Reproduced, with permission, from Hanna Damasio.)

A. Top: Three-dimensional MRI reconstruction of a lesion (an infarction) in the left frontal operculum (dark gray) in a patient with Broca aphasia. **Bottom:** Coronal MRI section of the same brain through the damaged area.

B. Top: Three-dimensional MRI overlap of lesions in 13 patients with Broca aphasia (red indicates that lesions in five or more patients share the same pixels). **Bottom:** Coronal MRI section of the same composite brain image through the damaged area.

cortical components of the network are located in lateral areas of the left frontal cortex (Brodmann's areas 47, 46, 9), the left parietal cortex (areas 40, 39), and sensorimotor areas above the Sylvian fissure between Broca's and Wernicke's regions (lower sector of areas 3, 1, 2, and 4). The critical subcortical component is in the left basal ganglia (head of the caudate nucleus and putamen). When damage is restricted to Broca's area alone or to its subjacent white matter, the result is the condition of Broca's area aphasia, a milder version of true Broca aphasia from which many patients are able to recover.

Wernicke Aphasia Results from Damage to Left Posterior Temporal Lobe Structures

The speech of patients with Wernicke aphasia is effortless, melodic, and produced at a normal rate, and is thus quite unlike that of patients with true Broca aphasia. The content of the speech, however, is often unintelligible because of frequent errors in the choice of words and phonemes, the order of which determines the word (Table 60-2).

Patients with Wernicke aphasia often shift the order of individual sounds and sound clusters, and add or subtract them to a word in a manner that distorts the intended phonemic plan. These errors are called *phonemic paraphasias* (paraphasia refers to any substitution of an erroneous phoneme or entire word for the intended, correct one). When phoneme shifts occur frequently and in close temporal proximity, words become unintelligible. Even when individual sounds are normally produced, Wernicke aphasics have great difficulty selecting words that accurately represent their intended meaning (known as a verbal or semantic paraphasia). For example, a patient might say *headman* when he means *president*.

Wernicke aphasics have difficulty comprehending the sentences uttered by others. Although this deficit is suggested by the Wernicke-Geschwind model, Wernicke's area is no longer seen as the center of auditory comprehension. The modern view is that Wernicke's area is part of a system that associates speech sounds with concepts. This system includes, in addition to Wernicke's area, the many parts of the brain that subserve grammar, attention, and the knowledge that is the source of the meanings of the words in the sentences.

Wernicke aphasia is usually caused by damage to the posterior section of the left auditory association cortex (Brodmann's area 22), although in severe and persisting cases there is involvement of the middle temporal gyrus and deep white matter (Figure 60-7).

Conduction Aphasia Results from Damage to a Specific Sector of Posterior Language Areas

Patients with conduction aphasia comprehend simple sentences and produce intelligible speech. However, like Broca and Wernicke aphasias, they cannot repeat sentences verbatim, they cannot assemble phonemes effectively (and thus produce many phonemic paraphasias) and cannot easily name pictures and objects. Speech production and auditory comprehension are less compromised than in the two other major aphasias (Table 60-2).

Persistent conduction aphasia is caused by damage to the left superior temporal gyrus and the inferior parietal lobe (Brodmann's areas 39 and 40). The damage can extend to the left primary auditory cortex (Brodmann's areas 41 and 42), the insula, and the underlying white matter.

A recent study by Buchsbaum and colleagues points to a specific subterritory, area Spt located at the boundary of areas 39 and 40, as the region of maximal lesion overlap in cases of conduction aphasia. Area Spt exhibits both auditory and motor responses. In brief, no evidence supports Wernicke's idea that conduction aphasia is caused by a simple interruption or disconnection of the arcuate fasciculus alone. The damage does compromise white matter, as Wernicke predicted, and destroys feed-forward and feedback projections that interconnect areas of temporal, parietal, insular, and frontal cortex. This connectional system seems to be part of the network required to assemble phonemes into words and to coordinate speech articulation.

In spite of the fact that the exact anatomical correlates of conduction aphasia are being revised and that the mechanism of the defect now appears more complex than that proposed in the Wernicke-Geschwind model, it is interesting to note that Wernicke correctly predicted both the main signs of the syndrome and the approximate location of the correlated lesion. The general model still holds.

Global Aphasia Results from Widespread Damage to Several Language Centers

Global aphasics are almost completely unable to comprehend language or formulate and repeat sentences, thus combining features of Broca, Wernicke, and conduction aphasias. Speech is reduced to a few words at best. The same word might be used repeatedly, appropriately or not, in a vain attempt to communicate an idea. Nondeliberate ("automatic") speech may be preserved, however. This includes stock expletives (which are used appropriately and with normal phonemic,

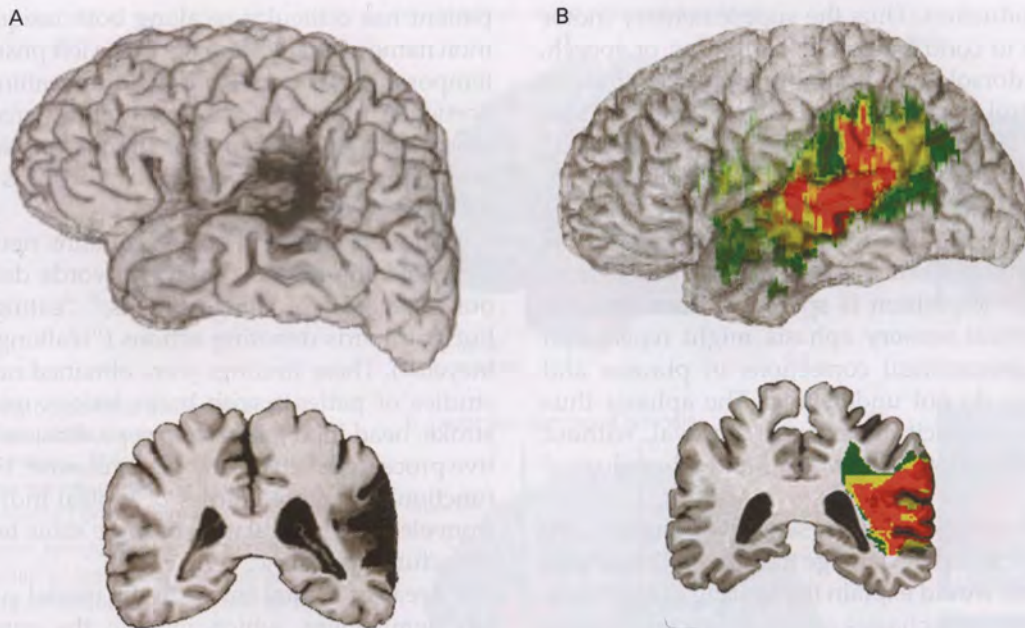


Figure 60-7 Sites of lesions in Wernicke aphasia.

A. Top: Three-dimensional MRI reconstruction of a lesion (an infarction) in the left posterior and superior temporal cortex (dark gray) in a patient with Wernicke aphasia. **Bottom:** Coronal MRI section of the same brain through the damaged area.

B. Top: Three-dimensional MRI overlap of lesions in 13 patients with Wernicke aphasia, obtained with the MAP-3 technique (red indicates that five or more lesions share the same pixels). **Bottom:** Coronal MRI section of the same composite brain image through the damaged area.

phonetic, and inflectional structures), routines such as counting or reciting the days of the week, and the ability to sing previously learned melodies and their lyrics. Auditory comprehension is limited to a small number of words and idiomatic expressions.

Classic global aphasia is accompanied by weakness in the right side of the face and paralysis of the right limbs. It involves damage in three regions: damage to the anterior language region and the basal ganglia and insula, leading to Broca aphasia; damage to the auditory areas of cortex, leading to conduction aphasia; and damage to the posterior language regions, producing Wernicke aphasia. Such widespread damage can only be caused by a stroke in the region supplied by the middle cerebral artery (Appendix C).

Transcortical Aphasias Result from Damage to Areas Near Broca's and Wernicke's Areas

The Wernicke-Geschwind model predicts that aphasias can be caused not only by damage to components of the language system but also to areas and pathways that connect those components to the rest of the brain. Patients with transcortical motor aphasia, such as

Broca aphasics, speak nonfluently, but they can *repeat* sentences, even very long sentences.

Transcortical motor aphasia has been linked to damage to the left dorsolateral frontal area, a patch of association cortex anterior and superior to Broca's area, although there can be substantial damage to Broca's area itself. The left dorsolateral frontal cortex is involved in the allocation of attention and the maintenance of higher executive abilities, including the selection of words. For example, part of the left dorsolateral frontal cortex is activated in functional neuroimaging studies when subjects have to produce the names or actions associated with particular objects (eg, saying "kick" in response to "ball"), and damage to it leaves a patient unable to perform such a task, although they can produce words in ordinary conversation.

The aphasia can also be caused by damage to the left supplementary motor area, located high in the frontal lobe, directly in front of the primary motor cortex and buried mesially between the hemispheres. Electrical stimulation of the area in nonaphasic surgery patients causes the patients to make involuntary vocalizations or to be unable to speak, and functional neuroimaging studies have shown it to be activated

in speech production. Thus the supplementary motor area appears to contribute to the initiation of speech, whereas the dorsolateral frontal regions contribute to ongoing control of speech, particularly when the task is difficult.

Transcortical sensory aphasics have fluent speech, impaired comprehension, and great trouble naming things. The aphasia differs from Wernicke aphasia in the same way that transcortical motor aphasia differs from Broca aphasia: Repetition is spared. In fact, patients with transcortical sensory aphasia might repeat and even make grammatical corrections in phrases and sentences they do not understand. The aphasia thus appears to be a deficit in semantic retrieval, without significant disruption of syntactic and phonological abilities.

Transcortical motor and sensory aphasias are believed to be caused by damage that spares the arcuate fasciculus. This would explain the sparing of repetition skills. Transcortical aphasias are thus the complement of conduction aphasia, behaviorally and anatomically. Transcortical sensory aphasia appears to be caused by damage to parts of the junction of the temporal, parietal, and occipital lobes, which connect the perisylvian language areas with the parts of the brain responsible for word meaning.

Finally, the growing attention given to degenerative brain conditions has permitted a characterization of the primary progressive aphasias (PPA). Their presentation tends to correspond to that of the classical aphasias. The main variants of PPA, as classified by Maria Luisa Gorno-Tempini and colleagues, are *nonfluent/agrammatic, semantic, and logopenic*.

The Classical Aphasias Have Not Implicated All Brain Areas Important for Language

The cortical sites damaged in the classical aphasias comprise only a portion of language-related areas in the brain. More recent research on aphasia has uncovered several other language-related regions in the cerebral cortex and in subcortical structures. For example, the anterior temporal and inferotemporal cortex have only recently become associated with language.

Damage to the *left* temporal cortex, in Brodmann's areas 21, 20, and 38, causes severe and pure naming defects—impairments of word retrieval without any accompanying grammatical, phonemic, or phonetic difficulty. When the damage is confined to the left temporal pole (Brodmann's area 38), the patient has difficulty recalling the names of unique places and persons but not names for common entities. When the lesions involve the mid temporal sector (areas 21 and 20), the

patient has difficulty recalling both unique and common names. Finally, damage to the left posterior inferotemporal sector causes a deficit in recalling words for particular types of items—tools and utensils—but not words for natural things or unique entities. Recall of words for actions or spatial relationships is not compromised (Figure 60–8).

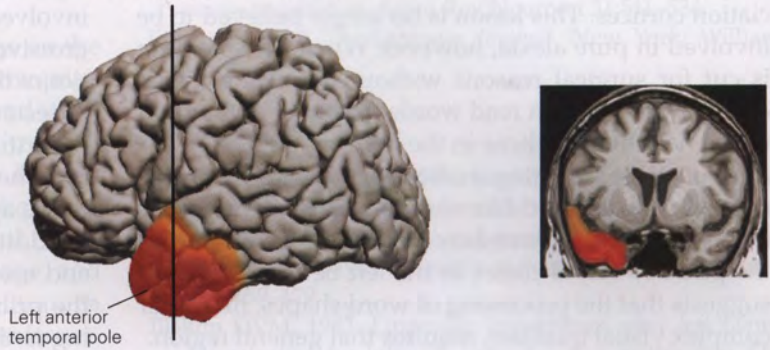
The left temporal cortex contains neural systems that hold the key to retrieving words denoting various categories of things (“tools,” “eating utensils”), but not words denoting actions (“walking,” “riding a bicycle”). These findings were obtained not only from studies of patients with brain lesions resulting from stroke, head injury, herpes encephalitis, and degenerative processes such as Alzheimer disease, but also from functional imaging studies of typical individuals and from electrical stimulation of these same temporal cortices during surgery.

Areas of frontal cortex in the mesial surface of the left hemisphere, which include the supplementary motor area and the anterior cingulate region (known as Brodmann's area 24), play an important role in the initiation and continuation of speech. Damage in these areas impairs the initiation of movement (akinesia) and causes mutism, a complete absence of speech. In aphasic patients the complete absence of speech is a rarity and is only seen during the very early stages of the condition. Patients with akinesia and mutism fail to communicate by words, gestures, or facial expression because the drive to communicate is impaired, not because the neural machinery of expression is damaged as in aphasia.

Damage to the left subcortical gray nuclei impairs grammatical processing in both speech and comprehension. The basal ganglia are closely interconnected with the frontal and parietal cortex and may have a role in assembling morphemes into words and words into sentences, just as they serve to assemble the components of complex movements into a smooth whole.

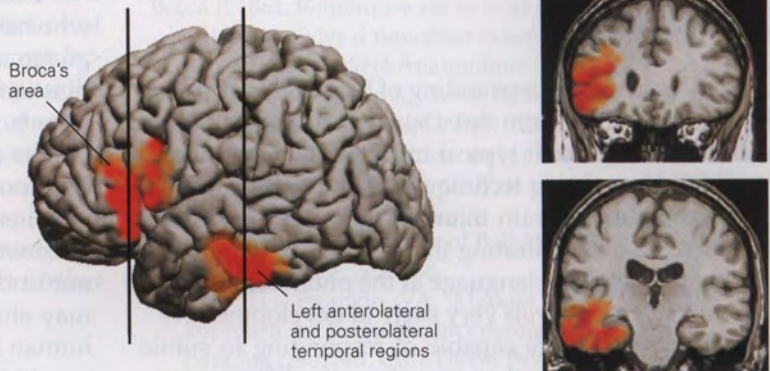
Certain brain lesions in adults can cause *alexia*, a disruption of the ability to read, or *agraphia*, a disruption of the ability to write (also known as word blindness). The two disorders may appear combined or separately, and they may or may not be associated with aphasia depending on the site of the causative lesion. Given the very recent emergence of writing (less than 5,000 years ago), and the even more recent emergence of near universal literacy (probably less than a century ago), it is unlikely that a special reading system evolved in the human brain in such a short period of evolutionary time. Therefore pure alexia without aphasia cannot be attributed to impairment of a

A Defective naming of unique images



Left anterior temporal pole

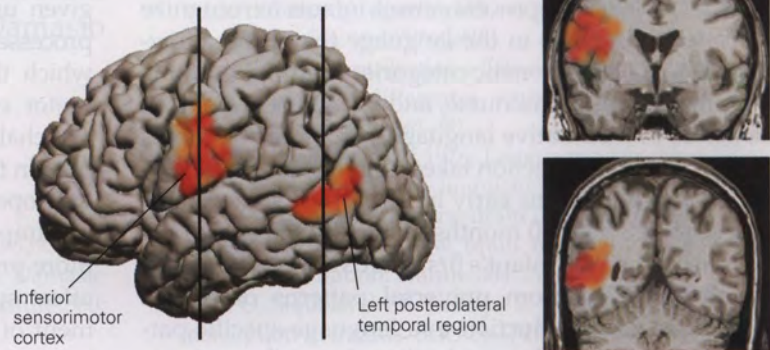
B Defective naming of animals



Broca's area

Left anterolateral and posterolateral temporal regions

C Defective naming of tools



Inferior sensorimotor cortex

Left posterolateral temporal region

Figure 60-8 Regions of the brain other than Broca's and Wernicke's areas involved in language processing. The study used functional magnetic resonance imaging (fMRI) to study patients with selected brain lesions.

- A. The left anterior temporal pole is the region of maximal overlap of lesions associated with impaired naming of unique images, such as the face of a person.
- B. The left anterolateral and posterolateral temporal regions as well as Broca's region are the sites of maximal overlap of lesions associated with impaired naming of nonunique animals.
- C. The left motor cortex and left posterolateral temporal cortex are the sites of maximal overlap of lesions associated with deficits in naming of tools.

special reading system in the brain, and is more likely to be caused by a disconnection between the visual and language systems.

Because vision is a bilateral brain process while language is lateralized, pure alexia requires a disruption in the transfer of visual information to the language areas of the left hemisphere. In 1892 the French neurologist Jules Dejerine studied an intelligent and highly articulate man who had recently lost the ability to read, even though he could spell, understand words spelled

to him, copy written words, and recognize them after writing the individual letters. The patient could not see color in his right visual field, but his vision was otherwise intact in both visual fields.

Postmortem examination revealed damage in a region of the left occipital region that disrupted the transfer of visually related signals from *both* the left and right visual cortex to language areas in the left hemisphere. The postmortem also revealed some damage to the splenium, the posterior portion of the corpus

callosum that interconnects left and right visual association cortices. This lesion is no longer believed to be involved in pure alexia, however. When the splenium is cut for surgical reasons without damaging visual cortices, patients can read words normally in the right visual field but not those in the left.

Functional imaging studies have shown that reading words and word-like shapes selectively activates extrastriate areas (secondary visual cortex) anterior to the primary visual cortex in the left hemisphere. This suggests that the processing of word shapes, like other complex visual qualities, requires that general region.

An Overall View

Advances in our understanding of language processing by the brain come from three sources: its acquisition in children, its study in typical individuals using noninvasive brain imaging techniques, and its dissolution in patients suffering brain injury. Studies on infants and children are demonstrating that children, even infants, master the details of language at the phonological, lexical, and syntactic levels very early in development.

Infants begin life capable of responding to subtle acoustic distinctions that cue phonetic differences in the world's languages, distinctions that likely capitalize on general auditory perceptual processes. Very rapidly, a powerful learning process causes infants to recognize statistical properties in the language they hear, allowing them to form phonetic categories, find words in the ongoing stream of discourse, and recognize the phrase structure of their native language, all before 10 months of age. Speech production takes a similar course, showing universal patterns early in life, which show differentiation by about 10 months of age. By the end of the first year, when the infant's first words appear, language learning evolves from universal patterns of speech perception and production to a language-specific pattern. Infant-directed speech ("motherese"), with its enhanced prosodic cues and its exaggerated phonetic units, may assist language learning in the young.

Early language learning being documented in experiments on infants and young children is unrelated to external reinforcement of the kind described by Skinner. Nor does it conform to the process described by Chomsky, by which innately provided options are chosen (or maintained) on the basis of experience. Infant language learning involves a more general sensory and cognitive ability that fine tunes the brain and alters both speech perception and production very early.

The processing of a native language differs from the processing of a foreign language. Taken together,

studies show that highly diverse brain regions are involved in language processing and represent a progressive neural commitment to the features and properties of the native language. These findings, and studies of second language acquisition, suggest new models of the critical or sensitive period for language acquisition.

The difficulty in learning a second language later in life appears to be related to experience or expertise, in addition to age of acquisition. Language experience and use commit brain structure to patterns that reflect the primary language so that second language learning is difficult to the degree that it employs a totally different set of phonological and grammatical rules.

Behavioral and brain studies of infants and adults who have been systematically exposed to a foreign language are likely to elucidate the nature of the brain's plasticity for language over a lifetime. Studies of infants who are being raised in bilingual or trilingual homes are likely to answer questions about whether the human brain has limitless potential for language, or whether our ability to acquire multiple languages is constrained. These studies will not only advance our understanding of the neural basis of language but may elucidate general biological principles regarding human learning.

At the same time, studies on the nature of language dissolution in aphasia have made great progress since Broca's and Wernicke's seminal discoveries. They have given us a more complete understanding of linguistic processes and an appreciation of the complex ways in which they interconnect with systems for perception, motor control, conceptual knowledge, and intentions. The challenges to elucidating the neural basis of language remain formidable, although several developments offer the hope of continued progress in the near future.

Improvements in structural imaging will allow more precise and consistent delineation of lesions that affect specific features of language ability. Measurement of brain activity in typical subjects will become increasingly important in the future, as both the spatial and temporal resolution of these techniques improve and the experimental paradigms used to study language become more productive. Neurosurgical candidates whose brain functions must be mapped by stimulation during surgery or by recording from implanted electrode grids that remain in place during everyday activities will be an important source of fine-grained information.

Nevertheless, the data available from the past decade of research already suggest two important insights, as noted by Greg Hickok and David Poeppel: The recruitment of brain regions in language studies is highly dependent on the tasks used in the experiment,

and language reception may be more bilaterally organized than previously appreciated.

A promising approach is to relate findings on the developmental time course of human language acquisition, plasticity for second language learning, and studies on language dissolution caused by brain trauma. Are the components of language that are learned earliest—those involving prosodic and phonetic learning in speech perception and production—most resistant to change when learning a second language, and also the least likely to suffer from the effects of trauma to the brain? Future research will address these issues.

Understanding the human capacity for language is important for the advancement of fundamental neuroscience and indispensable for the treatment of patients with aphasia, which is one of the most frequent impairments of higher function caused by stroke and head injury (the others are impairments of memory, emotion, and decision making). The astonishing feat of language is too complex to be understood with the tools of any single academic or medical specialty and, as several disciplines come together to study the underlying neural processes, we should expect further significant breakthroughs.

Patricia K. Kuhl
Antonio R. Damasio

Selected Readings

- Damasio AR. 1992. Aphasia. *N Engl J Med* 326:531–539.
- Damasio H, Grabowski TJ, Tranel D, Hichwa R, Damasio AR. 1996. A neural basis for lexical retrieval. *Nature* 380:499–505.
- Damasio H, Tranel D, Grabowski TJ, Adolphs R, Damasio AR. 2004. Neural systems behind word and concept retrieval. *Cognition* 92:179–229.
- Doupe A, Kuhl PK. 1999. Birdsong and speech: common themes and mechanisms. *Annu Rev Neurosci* 22:567–631.
- Gopnik A, Meltzoff AN, Kuhl PK. 2001. *The Scientist in the Crib: What Early Learning Tells Us About the Mind*. New York: Harper Collins.
- Hauser M, Chomsky N, Fitch T. 2002. The faculty of language: what is it, who has it, and how did it evolve? *Science* 298:1569–1579.
- Hickok G, Poeppel D. 2007. The cortical organization of speech processing. *Nat Rev Neurosci* 8:393–402.
- Kuhl PK. 2004. Early language acquisition: cracking the speech code. *Nat Rev Neurosci* 5:831–843.
- Kuhl PK, Rivera-Gaxiola M. 2008. Neural substrates of language acquisition. *Annu Rev Neurosci* 31:511–534.
- Pinker S. 1994. *The Language Instinct*. New York: William Morrow.

References

- Bates E, Wulfeck B, MacWhinney B. 1991. Cross-linguistic research in aphasia: an overview. *Brain Lang* 41:123–148.
- Baynes K. 1990. Language and reading in the right hemisphere: highways or byways of the brain? *J Cogn Neurosci* 2:159–179.
- Bishop DVM. 1983. Linguistic impairment after left hemidecortication for infantile hemiplegia. A reappraisal. *Q J Exp Psychol* 35A:199–207.
- Broca P. 1861. Remarques sur le siège de la faculté du langage articulé, suivies d'une observation d'aphémie (perte de la parole). *Bull Société Anatomique de Paris* 6:330–357.
- Buchsbaum BR, Baldo J, Okada K, Berman KF, Dronkers N, D'Esposito M, Hickok G. 2011. Conduction aphasia, sensory-motor integration, and phonological short-term memory—an aggregate analysis of lesion and fMRI data. *Brain Lang* 119:119–128.
- Chomsky N. 1959. A review of B. F. Skinner's "Verbal Behavior." *Language* 35:26–58.
- Cornell TL, Fromkin VA, Mauner G. 1993. A linguistic approach to language processing in Broca's aphasia: a paradox resolved. *Curr Direct Psych Sci* 2:47–52.
- Damasio AR, Damasio H. 1992. Brain and language. *Sci Am* 267:89–95.
- Damasio AR, Tranel D. 1993. Nouns and verbs are retrieved with differently distributed neural systems. *Proc Natl Acad Sci U S A* 90:4957–4960.
- Dejerine J. 1892. Contribution à l'étude anatomopathologique et clinique des différentes variétés de cécité verbale. *Memoires Soc Biol* 4:61–90.
- Dennis M, Whitaker HA. 1976. Language acquisition following hemidecortication: linguistic superiority of the left over the right hemisphere. *Brain Lang* 3:404–433.
- Dronkers NF. 1996. A new brain region for coordinating speech articulation. *Nature* 384:159–161.
- Eimas PD, Siqueland ER, Jusczyk P, Vigorito J. 1971. Speech perception in infants. *Science* 171:303–306.
- Fernald A, Kuhl P. 1987. Acoustic determinants of infant preference for Motherese speech. *Infant Behav Dev* 10:279–293.
- Flege JE. 1995. Second language speech learning: theory, findings, and problems. In: W. Strange (ed). *Speech Perception and Linguistic Experience*, pp. 233–277. Timonium, MD: York Press.
- Flege JE, Yeni-Komshian GH, Liu S. 1999. Age constraints on second-language acquisition. *J Mem Lang* 41:78–104.
- Fromkin V, Rodman R. 1997. *An Introduction to Language*, 6th ed. New York: Harcourt Brace Jovanovich.
- Galaburda AM. 1994. Developmental dyslexia and animal studies: at the interface between cognition and neurology. *Cognition* 50:133–149.
- Gandour J, Wong D, Hsieh L, Weinzapfel B, Van Lancker D, Hutchins GD. 2000. A crosslinguistic PET study of tone perception. *J Cogn Neurosci* 12:207–222.

- Gardner H, Brownell H, Wapner W, Michelow D. 1983. Missing the point: the role of the right hemisphere in the processing of complex linguistic materials. In: E. Perelman (ed). *Cognitive Processes in the Right Hemisphere*, pp. 169–192. New York: Academic Press.
- Geschwind N. 1970. The organization of language and the brain. *Science* 170:940–944.
- Geschwind N. 1965. Disconnexion syndromes in animals and man. *Brain* 88:585–644.
- Goodglass H. 1993. *Understanding Aphasia*. San Diego: Academic Press.
- Gorno-Tempini ML, Hillis AE, Weintraub S, Kertesz A, Mendez M, Cappa SF, et al. 2011. Classification of primary progressive aphasia and its variants. *Neurol* 76: 1006–1014.
- Imada T, Zhang Y, Cheour M, Tualal S, Ahonen A, Kuhl PK. 2006. Infant speech perception activates Broca's area: a developmental magnetoencephalography study. *Neuroreport* 17:957–962.
- Iverson P, Kuhl PK, Akahane-Yamada R, Diesch E, Tohkura Y, Kettermann A, Siebert C. 2003. A perceptual interference account of acquisition difficulties for non-native phonemes. *Cognition* 87:B47–57.
- Johnson J, Newport E. 1989. Critical period effects in sound language learning: the influence of maturation state on the acquisition of English as a second language. *Cognit Psychol* 21:60–99.
- Jusczyk PW, Friederici AD, Wessels JMI, Svenkerud VY, Jusczyk AM. 1993. Infants' sensitivity to the sound patterns of native language words. *J Mem Lang* 32:402–420.
- Knudsen EI. 2004. Sensitive periods in the development of the brain and behavior. *J Cogn Neurosci* 16:1412–1425.
- Kuhl PK. 2000. A new view of language acquisition. *Proc Natl Acad Sci U S A* 97:11850–11857.
- Kuhl PK, Andruski J, Christovich I, Chistovich L, Kozhevnikova E, Ryskina V, Stolyarova E, Sungberg U, Lacerda F. 1997. Cross-language analysis of phonetic units in language addressed to infants. *Science* 277:684–686.
- Kuhl PK, Tsao F-M, Liu H-M. 2003. Foreign-language experience in infancy: effects of short-term exposure and social interaction on phonetic learning. *Proc Natl Acad Sci U S A* 100:9096–9101.
- Kuhl PK, Williams KA, Lacerda F, Stevens KN, Lindblom B. 1992. Linguistic experience alters phonetic perception in infants by 6 months of age. *Science* 255:606–608.
- Lenneberg E. 1967. *Biological Foundations of Language*. New York: Wiley.
- Lesser RP, Arroyo S, Hart J, Gordon B. 1994. Use of subdural electrodes for the study of language functions. In: A. Kertesz (ed). *Localization and Neuro-Imaging in Neuropsychology*, pp. 57–72. San Diego: Academic Press.
- Linebarger M, Schwartz M, Saffran E. 1983. Sensitivity to grammatical structure in so-called agrammatic aphasics. *Cognition* 13:361–392.
- Liu H-M, Kuhl PK, Tsao F-M. 2003. An association between mothers' speech clarity and infants' speech discrimination skills. *Dev Sci* 6:F1-F10.
- Mazoyer BM, Tzourio N, Frak V, Syrota A, Murayama N, Levrrier O, Salamon G, Dehaene S, Cohen L, Mehier J. 1993. The cortical representation of speech. *J Cogn Neurosci* 5:467–479.
- Miyawaki K, Strange W, Verbrugge R, Liberman AM, Jenkins JJ, Fujimura O. 1975. An effect of linguistic experience: the discrimination of [r] and [l] by native speakers of Japanese and English. *Percept Psychophys* 18:331–340.
- Neville HJ, Coffey SA, Lawson D, Fischer A, Emmorey K, Bellugi U. 1997. Neural systems mediating American Sign Language: effects of sensory experience and age of acquisition. *Brain Lang* 57:285–308.
- Newport EL, Aslin RN. 2004. Learning at a distance I. Statistical learning of non-adjacent dependencies. *Cogn Psychol* 48:127–162.
- Ojemann G. 1994. Cortical stimulation and recording in language. In: A. Kertesz (ed). *Localization and Neuroimaging in Neuropsychology*, pp. 35–55. San Diego: Academic Press.
- Penfield W, Roberts L. 1959. *Speech and Brain Mechanisms*. Princeton, NJ: Princeton University Press.
- Peterson SE, Fox PT, Posner MI, Mintun M, Raichle ME. 1988. Positron emission tomographic studies of the cortical anatomy of single-word processing. *Nature* 331:585–589.
- Pettito LA, Holowka S, Sergio LE, Levy B, Ostry DJ. 2004. Baby hands that move to the rhythm of language: hearing babies acquiring sign language babble silently on the hands. *Cognition* 93:43–73.
- Saffran JR, Aslin RN, Newport EL. 1996. Statistical learning by 8-month old infants. *Science* 274:1926–1928.
- Silva-Pereyra J, Rivera-Gaxiola M, Kuhl PK. 2005. An event-related brain potential study of sentence comprehension in preschoolers: semantic and morphosyntactic processing. *Cogn Brain Res* 23:247–258.
- Skinner BF. 1957. *Verbal Behavior*. Acton, MA: Copely Publishing Group.
- Stromswold K, Caplan D, Alpert N, Rauch S. 1996. Localization of syntactic comprehension using positron emission tomography. *Brain Lang* 52:452–473.
- Tsao F-M, Liu H-M, Kuhl PK. 2004. Speech perception in infancy predicts language development in the second year of life: a longitudinal study. *Child Dev* 75: 1067–1084.
- Wernicke C. 1874. *Der Aphasische Symptomenkomplex*. Breslau: Kohn und Weigert.
- Wertz RT, LaPointe LL, Rosenbek JC. 1984. *Apraxia of Speech in Adults: The Disorder and Its Management*. Orlando: Grune and Stratton.
- Yeni-Komshian G, Flege JE, Liu S. 2000. Pronunciation proficiency in the first and second languages of Korean-English bilinguals. *Biling Lang Cogn* 3:131–149.
- Zaidel E. 1990. Language functions in the two hemispheres following complete commissurotomy and hemispherectomy. In: F. Boiler, J. Grafman (eds). *Handbook of Neuropsychology*. New York: Elsevier.
- Zurif EB, Caramazza A, Meyerson R. 1972. Grammatical judgments of agrammatic aphasics. *Neuropsychology* 10:405–417.