10

Language Processing and the Human Brain

> No doubt a reasonable model of language use will incorporate, as a basic component, the generative grammar that expresses the speaker-hearer's knowledge of the language; but this generative grammar does not, in itself, prescribe the character or functioning of a perceptual model or a model of speech production.

NOAM CHOMSKY, *Aspects of the Theory of Syntax*, 1965

The Human Mind at Work

Psycholinguistics is an area of experimental linguistics that is concerned with linguistic performance—how we use our linguistic competence—in speech (or sign) production and comprehension. The human brain not only acquires and stores the mental lexicon and grammar, but also accesses that linguistic storehouse to speak and understand language in real time.

When we speak, we access our lexicon to find the words, and we use the rules of grammar to construct novel sentences and to produce the sounds that express them. When we listen to speech we also access the lexicon and grammar to assign a structure and meaning to the sequence of words we hear. We also connect the sentences we hear into a mental model of the discourse relying on both our linguistic and real-world knowledge.

The grammar relates sounds and meanings, and contains the units and rules of the language that make speech production and comprehension possible. However, other psychological processes are also involved in the production and comprehension of language. Various mechanisms enable us to break the continuous stream of speech sounds into linguistic units such as phonemes, syllables, and words in order to comprehend a message and to compose sounds into words in order to produce meaningful speech. Other cognitive mechanisms determine how we pull words from the mental lexicon, and still others explain how we assemble these words into a structural representation.

Ordinarily we have no difficulty understanding or producing sentences. We do it without effort or conscious awareness of the processes involved. However, we have all had the experience of making a speech error, or having a word on the "tip of our tongue," or failing to understand a perfectly grammatical sentence such as (1):

1. The horse raced past the barn fell.

On hearing this sentence many individuals will judge it to be ungrammatical; yet they will judge as grammatical a sentence with the same syntactic structure, such as (2):

2. The bus driven past the school stopped.

Similarly, people will have no problem with sentence (3), which has the same meaning as (1).

3. The horse that was raced past the barn fell.

Conversely, some ungrammatical sentences are easily understandable, such as sentence (4). This mismatch between grammaticality and interpretability tells us that language processing involves more than grammar.

4. *The baby seems sleeping.

A theory of linguistic performance tries to detail the psychological mechanisms that work with the grammar to facilitate language production and comprehension.

Comprehension

"I quite agree with you," said the Duchess; "and the moral of that is—'Be what you would seem to be'—or, if you'd like it put more simply—'Never imagine yourself not to be otherwise than what it might appear to others . . . to be otherwise.'"

"I think I should understand that better," Alice said very politely, "if I had it written down: but I can't quite follow it as you say it."

LEWIS CARROLL, *Alice's Adventures in Wonderland*, 1865

The sentence uttered by the Duchess is another example of a grammatical sentence that is difficult to understand. The sentence is very long and difficult to process because of the double negation and the multiple use of *otherwise*. Alice notes that if she had a pen and paper she could "unpack" this sentence more easily. The different kinds of breakdowns in performance, such as tip of the tongue phenomena, speech errors, and failure to comprehend tricky sentences, can tell us a great deal about the processes people normally use in speaking and understanding language, just as children's acquisition errors tell us a lot about the mechanisms involved in language development.

The Speech Signal

Understanding a sentence involves analysis at many levels. One of the first questions of linguistic performance concerns segmentation of the acoustic signal. How do we understand the individual speech sounds we hear? To understand this process, some knowledge of the signal can be helpful.

In Chapter 5, we described speech sounds according to the ways in which they are produced. These involve the position of the tongue, the lips, and the velum; the state of the vocal cords; whether the articulators obstruct the free flow of air; and so on. All of these articulatory characteristics are reflected in the sound wave itself and so speech sounds can also be described in physical or **acoustic** terms.

Physically, a sound is produced whenever there is a disturbance of air molecules. The ancient philosophers asked whether a sound is produced if a tree falls in the forest with no one to hear it. This question has been answered by the science of acoustics. Objectively, a sound is produced; subjectively, no sound is heard. In fact, there are sounds we cannot hear because our ears are not sensitive to the full range of frequencies. Many animals, such as dogs, hear a wider range of sounds than humans. *Acoustic phonetics* is concerned only with speech sounds, all of which can be heard by the normal human ear.

When we push air out of the lungs through the glottis, it causes the vocal cords to vibrate; this vibration in turn produces pulses of air that escape through the mouth (and sometimes the nose). These pulses are actually small variations in air pressure caused by the wavelike motion of the air molecules.

The sounds we produce can be described in terms of how fast the variations of the air pressure occur. This determines the **fundamental frequency** of the sounds and is perceived by the hearer as *pitch*. Along with fundamental frequency, when the vocal cords vibrate, they also produce a series of harmonics. A harmonic is a special frequency that is a multiple (2, 3, etc.) of the fundamental frequency. We can also describe the magnitude, or **intensity**, of the variations, which determines the loudness of the sound. The quality of the speech sound—whether it's an [i] or an [a] or whatever—is determined by the shape of the vocal tract when air is flowing through it. This shape modulates the strength of the harmonics into a spectrum of frequencies of greater or lesser intensity, and the particular combination of "greater or lesser" is heard as a particular sound. (Imagine smooth ocean waves with regular peaks and troughs approaching a rocky coastline. As they crash upon the rocks, they are "modulated" or broken up into dozens of "sub waves" with varying peaks and troughs. That is similar to what is happening to the glottal pulses as they "crash" through the vocal tract.)

Computer programs can be used to decompose the speech signal into its frequency components. When speech is fed into a computer (from a microphone or a recording), an image of the speech signal is displayed. The patterns produced are called **spectrograms** or more vividly, **voiceprints**.

A spectrogram of the words *heed, head, had,* and *who'd* is shown in Figure 10.1 (on the next page). Time in milliseconds is represented on the *x*-axis; frequency (pitch) is represented on the *y*-axis. The intensity of each frequency component is indicated by the degree of darkness: the more intense, the darker. Each vowel is characterized by dark bands, called **formants**, which differ in their placement

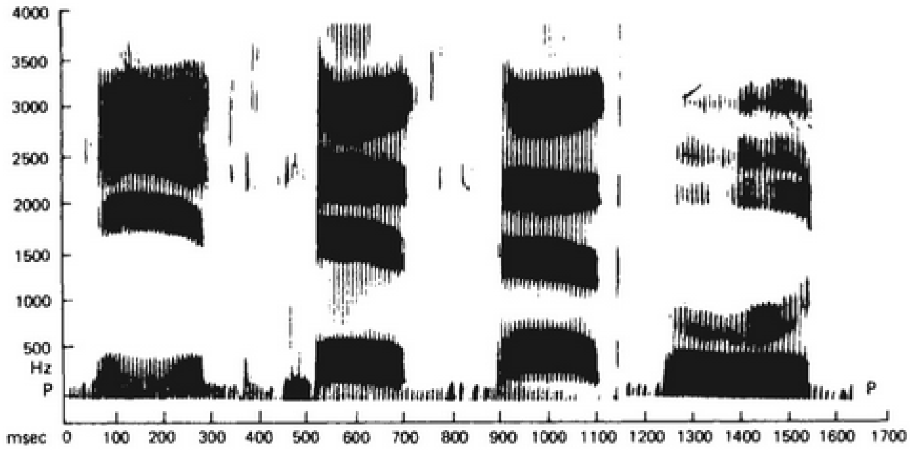


FIGURE 10.1 | A spectrogram of the words *heed*, *head*, *had*, and *who'd*, spoken with a British accent (speaker: Peter Ladefoged, February 16, 1973).
From LADEFOGED/JOHNSON. *A Course in Phonetics (with CD-ROM)*, 6E. © 2011 Cengage Learning. Reproduced by permission.

according to the particular vowel. They represent the strongest harmonics (or sub waves) produced by the shape of the vocal tract. Each vowel has its own formant frequencies, which account for the different vowel qualities you hear. The spectrogram also shows the pitch of the entire utterance (intonation contour) on the line marked P. The striations, or thin vertical lines, indicate a single opening and closing of the vocal cords. When the striations are far apart, the vocal cords are vibrating slowly and the pitch is low; when the striations are close together, the vocal cords are vibrating rapidly and the pitch is high.

By studying spectrograms of many different speech sounds, we can learn a great deal about the basic acoustic components produced by the various shapes of the vocal tract.

Speech Perception

> The mice think they are right, but my cat eats them anyways (sic) . . . perception is everything.
>
> TERRY GOODKIND (B. 1948)

Speech is a continuous signal. In natural speech, sounds overlap and influence each other, and yet listeners have the impression that they are hearing discrete units such as words, morphemes, syllables, and phonemes. A central problem of speech perception is to explain how listeners carve up the continuous speech signal into meaningful units. This is referred to as the "segmentation problem."

Another challenge is to understand how the listener manages to recognize particular speech sounds when they are spoken by different people and when they occur in different contexts. For example, how can a speaker tell that a [d] spoken by a man with a deep voice is the same unit of sound as the [d] spoken in the high-pitched voice of a child? Acoustically, they are distinct. Indeed, no two voices are identical in every detail. Similarly, a [d] that occurs before the vowel [i] is somewhat acoustically different from a [d] that occurs before the vowel [u]. Even within a single speaker the physical properties of the "same" sound vary from utterance to utterance depending on the phonological context and even the state of health of the speaker. How does a listener know that two physically distinct instances of a sound are the same? This is called the "lack of invariance problem."

Despite these problems, listeners are usually able to understand what they hear because our speech perception mechanisms are designed to overcome the variability and lack of discreteness in the speech signal. Experimental results show that listeners calibrate their perceptions to control for speaker differences, and can quickly adapt to foreign-accented or distorted speech. When listening to distorted speech, for example, listeners need to hear only two to four sentences to adjust, and can then generalize to words they have never heard before. It takes about a minute to adapt to non-native accents. Similarly, listeners adjust how they interpret timing information in the speech signal as a function of how quickly the speaker is talking. These *normalization* procedures enable the listener to understand a [d] as a [d] regardless of the speaker or speech rate. Listeners can exploit various acoustic cues in the signal, as well as relationships among different acoustic elements, to get around the lack of invariance problem. For example, the frequency of the first or lowest formant for /a/ is high relative to /i/ and /u/, though the precise values may differ among speakers. Additionally, certain types of speech sounds have characteristic properties that can be relied upon for identification. Stops have a brief period of silence followed by a burst; fricatives produce high-frequency noise; and vowels are associated with particular formant structures. These acoustic cues help listeners identify phonological units in the signal regardless of the speaker.

As we might expect, the units we perceive depend on the language we know, especially its phonemic inventory. For example, the initial consonant in [di], [da], and [du] are physically distinct from one another because of the formant transitions from the consonant to the different vowels—a coarticulation effect. Nevertheless, speakers perceive the [d]s as instances of the same phonological unit, namely the phoneme /d/. This phenomenon is known generally as **categorical perception**: Speakers perceive physically distinct stimuli as belonging to the same category because their perceptions are assisted by knowledge of the underlying classificatory system. In the case of language, varying sounds are ascribed to phonemes based on a speaker's knowledge of the phonology of his language. Categorical perception is one of the mechanisms that the speech perception system uses to deal with variability in the signal.

Similarly, speakers of English can perceive the difference between [l] and [r] despite their acoustic similarity because these phones represent distinct phonemes in the language. Speakers of Japanese have great difficulty in differentiating the two because in that language they are allophones of one phoneme. As we saw in our discussion of language development in Chapter 9, infants develop these different perceptual biases during the first year of life.

Returning to the segmentation problem, words and syntactic units such as phrases and sentences are seldom surrounded by boundaries such as pauses. Nevertheless, words are obviously units of perception. The spaces we put between them in writing supports this view. How do we find the words and syntactic constituents in the speech stream?

Stress and intonation provide some cues to these units. For example, in English 90% of the words used in conversation begin with a stressed syllable. Experiments have shown that when English listeners hear a stressed syllable, they are likely to treat it as the onset of a new word. Stress and intonation can also cue syntactic constituents. We know that the different meanings of the sentences *He lives in the white house* and *He lives in the White House* can be signaled by differences in their stress patterns. It is also true that syllables at the end of a phrase are longer in duration than at the beginning, and intonation contours mark clause boundaries. In addition, listeners use their lexical knowledge to identify words in the signal. This process is called **lexical access**, or word recognition, discussed in detail later.

Bottom-Up and Top-Down Models

> I have experimented and experimented until now I know that [water] never does run uphill, except in the dark. I know it does in the dark, because the pool never goes dry; which it would, of course, if the water didn't come back in the night. It is best to prove things by experiment; then you know; whereas if you depend on guessing and supposing and conjecturing, you will never get educated.
>
> MARK TWAIN, *Eve's Diary*, 1906

Language comprehension is very fast and automatic. We understand an utterance as fast as we hear it or read it. Ordinarily, we can process spoken language at a rate of around twenty phonemes per second. A visually impaired person who relies on a sped-up synthetic voice to read written material can comprehend speech at rates near one hundred phonemes per second. To a sighted person, this rate of speech would sound like chipmunks chattering.

Successful language comprehension requires that a lot of operations take place at once—what is called "parallel processing"—including the following: segmenting the continuous speech signal into phonemes, morphemes, words, and phrases; looking up the words and morphemes in the mental lexicon; finding the appropriate meanings of ambiguous words; placing them in a constituent structure; choosing among different possible structures when syntactic ambiguities arise; interpreting the phrases and sentences; making a mental model of the discourse and updating it to reflect the meaning of the new sentence; and factoring in the pragmatic context to assist with the other tasks.

To account for this vast amount of mental computation, and owing to the sequential nature of language, psycholinguists believe that listeners make guesses as to what and what not to expect next, thus eliminating unneeded processing. They suggest that perception and comprehension must involve both **top-down processing** and **bottom-up processing**.

Bottom-up processing moves step-by-step from the incoming acoustic signal, to phonemes, morphemes, words and phrases, and ultimately to semantic interpretation. The listener uses acoustic information to build a phonological representation of words that he can then look up in the lexicon. According to this model, the speaker waits until hearing an article followed by a noun and then constructs a noun phrase while awaiting the next word, and so on.

In top-down processing, the listener relies on higher-level semantic, syntactic, and contextual information to analyze the acoustic signal. For example, upon hearing the determiner *the*, the speaker expects the next word to be a noun or adjective rather than a verb or preposition. In this instance, the listener's knowledge of phrase structure would be the source of information.

Psycholinguists try to determine the extent to which comprehension is based solely on the acoustic signal (bottom up) and how much help comes from contextual (sentence or discourse) information (top down). When the acoustic signal is inadequate to understand a word or phrase, top-down information can enable the hearer to choose from among a range of possibilities. Evidence for top-down processing is found in experiments that require subjects to identify spoken words in noisy conditions. Listeners make more errors when the words occur in isolation than when they occur in sentences. Moreover, they make more errors if the words occur in nonsense sentences, and they make the most errors if the words occur in ungrammatical sentences.

Another source of evidence for top-down processing comes from **shadowing tasks** in which subjects are asked to repeat what they hear as promptly as possible. Subjects often produce words in anticipation of the input. They can guess what's coming next by having processed the sentence to that point. Fast shadowers often correct speech errors or mispronunciations unconsciously and add inflectional endings if they are absent, showing rapid processing of the structural relations of immediately preceding words. Corrections are more likely to occur when the target word can be predicted from what has been said previously.

Top-down processing is also supported by a different kind of experiment. Subjects hear recorded sentences in "noisy conditions" in which some part of the signal is removed and a cough or buzz is substituted, such as the boldfaced "s" in the sentence *The state governors met with their respective legislature***s** *convening in the capital city*. They "hear" the sentence without any phonemes missing, and have difficulty saying where in the word the noise occurred. This effect is called *phoneme restoration*. It appears that subjects can guess that the word containing the cough was *legislatures* and moreover, they truly believe they are hearing the [s] even when they're told it's not there. In this case, top-down information apparently overrides bottom-up information.

There is also a role for top-down information in segmentation. Sometimes an utterance can be divided in more than one way. For example, the phonetic sequence [grede] in a discussion of meat or eggs is likely to be heard as *Grade A*, but in a discussion of the weather as *grey day*.

In other cases, both bottom-up and top-down information may bear on the ultimate decision of what was spoken. Consider the sequence of phonemes /naɪtret/. It is compatible with two segmentations: [naɪtʰret] with an aspirated [tʰ] meaning "nitrate"; and [naɪtret] with an unaspirated [t] meaning "night rate." Bottom-up information such as the phonetic details of pronunciation can signal where the word boundary is. If the first /t/ is heard as aspirated, it must belong to the onset of the second syllable, so the decision is *nitrate*. If it is unaspirated, it must be part of the coda of the first syllable, so the decision is *night rate*.

But top-down information may also weigh in, so that [naɪtʰret] is favored following the word *sodium* or in the context of chemistry whereas [naɪtret] would be more plausible in the context of hotels. If the bottom-up cue is insufficient because of signal noise, or the top-down cue is vague because of an inconclusive context, then the other cue may weigh more heavily in the final decision.

None of this decision-making is conscious reasoning; it is all done for us by the grammatical engine that operates on the subconscious level.

Lexical Access and Word Recognition

Oh, are you from Wales?

Do you know a fella named Jonah?

He used to live in whales for a while.

GROUCHO MARX (1890–1977)

Psycholinguists have conducted a great deal of research on *lexical access* or *word recognition*, the process by which listeners obtain information about the meaning and syntactic properties of a word from their mental lexicon. Several different experimental techniques have been used in studies of lexical access.

One technique is to ask whether a string of letters or sounds is or is not a word. Subjects must respond by pressing one button if the stimulus is an actual word, and a different button if it is not, so they are making a **lexical decision**. During these and similar experiments, measurements of *response time* (RT) is taken. The assumption is that the longer it takes to respond to a particular task, the more processing is involved. RT measurements show that lexical access depends to some extent on the word's frequency of usage: More commonly used words such as *car* are responded to more quickly than words that are rarely encounter such as *cad*.

Lexical decision tasks can also provide information about how we use our phonological knowledge in lexical access. Studies show that listeners respond more slowly to "possible" non-words such as *floop* and *plim* than to "impossible" non-words such as *tlat* and *mrock*. The listener can quickly reject the impossible words based on phonotactic knowledge so that a lexical search is unnecessary. That possible and impossible non-words are processed differently is supported by brain imaging studies showing that the same areas of the brain are involved in accessing real words and possible non-words, while different areas respond to impossible non-words.

The speed with which a listener can retrieve a particular word also depends on the size of the word's phonological "neighborhood." A neighborhood is comprised of all the words that are phonologically similar to the target word. A word like *pat* has a dense neighborhood because there are many similar words—*bat*, *pad*, *pot*, *pit*, and so on, while a word like *crib* has far fewer neighbors. Words with larger neighborhoods take longer to retrieve than words from smaller ones because more phonological information is required to single out a word in a denser neighborhood.

Psycholinguists believe that each word in the mental lexicon is associated with a "resting level of activation," with some words more active than others. Each time the listener accesses a word its level rises a little bit. Thus, more frequently used words have a higher resting level of activation, and listeners show faster RTs to these words in decision tasks. Indeed, in reading tasks, subjects appear to "skip over" the short, high frequency function words, so quickly are they accessed. Top-down information may also play a role, allowing us quicker access to less frequent words when they are highly predictable from context.

Words can also be activated by hearing semantically related words. This effect is known as **semantic priming**. A listener will be faster at making a lexical decision on the word *doctor* if he has just heard *nurse* than if he just heard a semantically unrelated word such as *flower*. The word *nurse* is said to "prime" the word *doctor*. When we hear a priming word, related words are "awakened" and become more readily accessible for a few moments. This priming effect might arise because semantically related words are near each other or linked to each other in the mental lexicon. In bilinguals, a word may be primed in one language by a semantically related word in the other language. For example, in French-English bilinguals access to *cat* is facilitated by both *dog* and *chien*.

Morphological priming is a kind of semantic priming in which a morpheme of a multimorphemic sword primes a related word. For example, *sheepdog* primes *wool* as a result of *sheep*. Even when one morpheme is free and the other bound as in *runner*, the free morpheme *run* primes words like *race*. Stranger yet, even in pseudo-multimorphemic words such as *summer*, which does not mean "one who sums," the word "sum" is primed much as *paint* is primed by the word *painter*. These examples suggest that morphological decomposition is taking place automatically based on the phonetics of the word irrespective of the semantics.

Lexical decision techniques can be evaluated alongside results from brain studies to provide a more detailed understanding of the process of lexical access. In some cases, electrical brain activity in experimental subjects indicates that lexical access is occurring even though RT measurements do not. For example, *teach* may prime the related *taught* according to brain activity but not according to RT measurements. This result suggests that lexical decision occurs in stages, and that RT measurements are insensitive to earlier stages, whereas the brain measurements are taken continuously and reflect both earlier and later stages. (We discuss brain studies in more detail later in this chapter.)

Lexical ambiguities also provide important insights into how listeners access the mental lexicon. In certain experimental tasks, RTs are longer with ambiguous words than unambiguous ones, suggesting that ambiguous words require more processing resources. Indeed, studies show that listeners retrieve all meanings of an ambiguous word even when the sentence containing the word is biased toward one of the meanings. For example, when the word *palm* is heard in *The gypsy read the young man's palm* it primes both the word *hand* and the word *tree* according to RT measurements. The other meaning of *palm* (as in *palm tree*) is apparently activated even though that meaning is not a part of the meaning of the priming sentence. At a subsequent stage of processing—after about 250 milliseconds—the listener makes a decision about which meaning is the intended one based on the information in the rest of the sentence. This suggests that the initial accessing of a word is strictly bottom-up—every lexical entry that matches the phonological representation is activated—while the subsequent selection of the contextually appropriate meaning is a top-down process. Interestingly, young children do not show priming of all meanings of an ambiguous word, but only the most frequently used meaning. This is most likely because children have more limited processing resources than adults.

Syntactic Processing

Teacher Strikes Idle Kids

Enraged Cow Injures Farmer with Ax

Two Sisters Reunited after 18 Years in Checkout Counter

Stolen Painting Found by Tree

AMBIGUOUS HEADLINES

Understanding a sentence involves more than merely recognizing its individual words. The listener must also determine the syntactic relations among the words and phrases. This mental process, referred to as **parsing**, is largely governed by the rules of the grammar and strongly influenced by the sequential nature of language.

Listeners actively build a structural representation of a sentence as they hear it. They must therefore decide for each incoming word what its grammatical category is and how it fits into the structure that is being built. Often sentences present "temporary ambiguities" such as a word or words that belong to more than one syntactic category. For example, the string *The warehouse fires* . . . could continue in one of two ways:

1. . . . were set by an arsonist.
2. . . . employees over sixty.

Fires is a noun in sentence (1) and a verb in sentence (2). Experimental studies of such sentences show that both meanings and categories are activated when a subject encounters the ambiguous word. The ambiguity is quickly resolved based on syntactic and semantic context. Disambiguation is usually so fast and seamless that unintentionally ambiguous newspaper headlines such as those at the head of this section are scarcely noticeable except to the linguists who collect them.

Another important type of temporary ambiguity arises in cases in which the grammar permits a constituent to fit into a sentence in two different ways, as illustrated by the following example:

After the child visited the doctor prescribed a course of injections.

When readers encounter the phrase *the doctor* they immediately perceive it as the direct object of the verb *visit*. When they later come to the verb *prescribed*, they must "change their minds" or backtrack, and reanalyze *the doctor* as subject of a main clause instead. Sophisticated laboratory procedures that track the reader's eye movements can pinpoint difficult regions of the sentence and can see when the reader regresses to an earlier part of the sentence. Sentences that induce this backtracking effect are called **garden path sentences**. The sentence presented at the beginning of this chapter, *The horse raced past the barn fell*, is also a garden path sentence. People naturally interpret *raced* as the main verb, when in fact the main verb is *fell*.

The initial structural choices that lead people astray may reflect general principles that are used by the mental parser to deal with syntactic ambiguity. Two such principles are known as **minimal attachment** and **late closure**.

Minimal attachment says, "Build the simplest structure consistent with the grammar of the language." In the string *The horse raced* . . . , the simpler structure is the one in which *the horse* is the subject and *raced* the main verb; the less simple structure is similar to *The horse that was raced* . . . with *fell* as the main verb.

Late closure says "Attach incoming material to the phrase that is currently being processed," as the following sentence illustrates:

The doctor said the patient will die yesterday.

Readers often experience a garden path effect at the end of this sentence. The reader encounters *yesterday* nearest to the embedded clause *the patient will die*, which is closest to *yesterday*, and immediately tries to work it into the meaning. This fails because *yesterday* conflicts with the future marker *will* so the reader backtracks to attach *yesterday* to the main clause where it modifies *said*.

The syntactic parsing of sentences depends on different sources of information. The parser depends on the grammar to inform it as to how the incoming words can be grouped together into well-formed constituents. In cases of ambiguity, there are various structural possibilities to choose from. Principles such as "minimal attachment" and "late closure" guide the parser to choose the computationally simplest structure among the different grammatical possibilities. Garden path effects arise when listeners make a strong commitment to the simpler structure and are then "jarred" out of it by some kind of incongruity.

In some cases, frequency factors cause the reader to garden path, as illustrated by the following sentence:

The faithful people our church every Sunday.

People occurs much more frequently as a noun than a verb, leading the reader to initially analyze *the faithful people* as an NP, but this does not jibe with the rest of the sentence, which lacks a verb. The reader must backtrack and reanalyze *people* as the main verb meaning "to populate."

Other factors such as prosody, lexical biases, and even visual context can also influence the parser in its structural choices, and may even weaken the effects of the parsing principles. For example, the following sentence is ambiguous: Either the actress or the maid can be understood as the one on the balcony:

Someone photographed the maid of the actress who was on the balcony.

"Late closure" would place the actress on the balcony as the preferred interpretation. Studies show that placing an intonation pause after *the maid* greatly increases the chances of the listener assigning this meaning. On the other hand, a pause after *the actress* increases the likelihood of the interpretation where the maid is on the balcony.

Studies of other languages may call into question the universality of "late closure". Given the Spanish equivalent of the *actress-maid* type sentences, Spanish listeners prefer the interpretation in which the maid is on the balcony. Spanish speakers still obey late closure with other constructions, however.

Verb choice may also influence the parser's structural decisions. In a sentence such as (1) the processor is led to parse *the problem* as the direct object of the verb *understood* (minimal attachment) and will have to backtrack when *had no solution* is encountered, while in (2) such a garden path effect is less likely:

1. Tom understood the problem had no solution.
2. Tom thought the problem had no solution.

This is because the verb *understand* can be followed by both an NP and a sentence *(Tom understood the story, Tom understood the story was false)*, while the verb *think* can be followed by a sentence but not an NP. *(Tom thinks the story is crazy, *Tom thinks the story)*. The sentence processor is sensitive to subcategorization information in the lexical entries of verbs and also the frequency of occurrence of different contexts for particular verbs. (Subcategorization is discussed in Chapter 3.)

Surprisingly, the parser does not seem to make use of nonlinguistic information to make structural decisions. For example, you might think that a garden path is less likely in sentence (1) than sentence (2) because real-world knowledge tells us that performers are routinely sent flowers and florists routinely *send* them.

1. The performer sent the flowers was very pleased.
2. The florist sent the flowers was very pleased.

But this is not the case. Eye-tracking studies have shown that readers garden path equally on these two sentences despite the difference in plausibility.

However, in a different task, when readers are asked to paraphrase the two sentences, they do better with the more plausible *performer sent the flowers* sentence, indicating that nonlinguistic context facilitates comprehension at some point, though not at the parsing stage. Sentences that create problems for the parser, such as garden path sentences, tell us a great deal about how the sentence processor operates.

Another striking example of processing difficulty is illustrated by a rewording of a Mother Goose poem. In its original form we have:

> This is the dog that worried the cat that killed the rat that ate the malt that lay in the house that Jack built.

No problem understanding that. Now try this equivalent description:

> Jack built the house that the malt that the rat that the cat that the dog worried killed ate lay in.

No way, right?

Although the confusing sentence follows the rules of relative clause formation—you have little difficulty with *the cat that the dog worried*—it seems that once is enough; when you apply the same process twice, getting *the rat that the cat that the dog worried killed*, it becomes quite difficult to comprehend but perhaps possible. If we apply the process three times, as in *the malt that the rat that the cat that the dog worried killed ate*, all hope is lost.

The difficulty in parsing this kind of sentence is related to memory constraints. In processing the sentence, you have to keep *the malt* in mind all the way until *ate*, but while doing that you have to keep *the rat* in mind all the way until *killed*, and while doing that . . . It's a form of structure juggling that is difficult to perform; we evidently don't have enough of the right kind of memory capacity to keep track of all the necessary items. Though we have the competence to create such sentences, performance limitations prevent the creation and comprehension of such monstrosities.

The ability to comprehend what is said to us is a complex psychological process involving the internal grammar, parsing principles such as "minimal attachment" and "late closure", linguistic context, lexical information such as the subcategorization of verbs, prosody, frequency factors, and memory limitations.

Speech Production

> Speech was given to the ordinary sort of men, whereby to communicate their mind; but to wise men, whereby to conceal it.
>
> ROBERT SOUTH, sermon at Westminster Abbey, April 30, 1676

As we saw in the previous sections, the listener's job is to decode the intended meaning of a message from the speech signal produced by a speaker. The speaker's job is the reverse. He must encode an idea into an utterance using speech sounds and words (or signs) organized according to the grammatical structures of the language. It is more difficult to devise experiments that provide information about how the speaker proceeds than to do so for the listener's side of the process. Much of the best information about speech production has come from observing and analyzing spontaneous speech, especially speech errors.

Lexical Selection

> Humpty Dumpty's theory, of two meanings packed into one word like a portmanteau, seems to me the right explanation for all. For instance, take the two words "fuming" and "furious." Make up your mind that you will say both words but leave it unsettled which you will say first. Now open your mouth and speak. If . . . you have that rarest of gifts, a perfectly balanced mind, you will say "frumious."
>
> LEWIS CARROLL, Preface to *The Hunting of the Snark*, 1876

In our previous discussion of comprehension, we saw that semantically related words are activated or primed during lexical retrieval. In production, we see a similar effect with slips of the tongue or speech errors (see Chapter 6), especially word substitution errors. Word substitutions are seldom random; they show that in our attempt to express our thoughts, we may make an incorrect lexical selection based on partial similarity or relatedness of meanings. This is illustrated in the following examples:

Bring me a **pen.**	→ Bring me a **pencil.**
It stays **light** out late here.	→ It stays **dark** out late here.
Please set the **table.**	→ Please set the **chair.**
Are my **tires** touching the curb?	→ Are my **legs** touching the curb?

Blends (see Chapter 8), in which we produce part of one word and part of another, illustrate how we may select two or more words to express our thoughts and instead of deciding between them, we produce them as "portmanteaus," as Humpty Dumpty calls them. Such blends are illustrated in the following errors:

1.	splinters/blisters	→ splisters
2.	edited/annotated	→ editated
3.	a swinging/hip chick	→ a swip chick
4.	frown/scowl	→ frowl

These blend errors are typical in that the segments stay in the same position within the syllable as they were in the target words.

In comprehension, lexical retrieval is affected by the number of words that are phonologically related to the target: what we earlier referred to as "phonological neighborhoods." In production, speakers often make speech errors involving the substitution of a word that is phonologically related to the target but unrelated in meaning, as the following examples show:

Did you feed the **bunny?**	→ Did you feed the **banana?**
We need a few laughs to break up the **monotony**.	→ We need a few laughs to break up the **mahogany**.
The flood damage was so bad they had to **evacuate** the city.	→ The flood damage was so bad they had to **evaporate** the city.

Just as more common words are accessed faster in comprehension than less common, so are they retrieved more easily in production. Speakers come up with *knife* more quickly than *bayonet*, for example. This is shown in studies of speaker hesitations or pauses, which are more common before low frequency words.

It is not surprising that many of the same factors that influence the listener in comprehension also affect the speaker in production–semantic and phonological relatedness of words, and word frequency. Whether you are speaking or listening you are accessing the same mental lexicon.

Application and Misapplication of Rules

I thought . . . four rules would be enough, provided that I made a firm and constant resolution not to fail even once in the observance of them.

RENÉ DESCARTES, *Discourse on Method*, 1637

Spontaneous errors show that the rules of morphology and syntax are also applied (or misapplied) when we speak. It is difficult to see this process in normal error-free speech, but when someone says *groupment* instead of *grouping*, *ambigual* instead of *ambiguous*, or *bloodent* instead of *bloody*, it shows that regular rules are applied to combine morphemes and form possible but nonexistent words.

Errors may also involve inflectional rules. The UCLA professor who said **We swimmed in the pool* knows that the past tense of *swim* is *swam*, but he mistakenly applied the regular rule to an irregular form. We also see evidence of the order of application of morphophonemic rules in production. Consider the *a/an* alternation rule in English. Errors such as *a burly bird* for the intended *an early bird* show that the rule applies after the stage at which *early* has slipped to *burly*.

Similarly, an error such as *bin beg*, pronounced [bĩn bɛg] for the intended *Big Ben* [bɪg bɛ̃n] (made by an announcer during the 2012 Olympic Games in London) shows that allophonic rules apply after phonemes are misordered. If the allophonic nasalization rule applied before the reordering, the result would have been [bɪn bɛ̃g].

Planning Units

"U.S. Acres," Paws, Inc. All Rights Reserved

We might suppose that speakers' thoughts are simply translated into words one after the other via a semantic mapping process. Grammatical morphemes would be added as demanded by the syntactic rules of the language. The phonetic representation of each word in turn would then be mapped onto the neuromuscular commands to the articulators to produce the acoustic signal representing it.

We know, however, that this is not a true picture of speech production. Although sounds within words and words within sentences are linearly ordered, speech errors or slips of the tongue show that the prearticulation or planning stages involve units larger than the single phonemic segment or even the word, as illustrated by the "U.S. Acres" cartoon. That error is an example of a **spoonerism**, named after William Archibald Spooner, a distinguished dean of an Oxford college in the early 1900s who is reported to have referred to Queen Victoria as "That queer old dean" instead of "That dear old queen," and berated his class of students by saying, "You have hissed my mystery lecture. You have tasted the whole worm," instead of the intended "You have missed my history lecture. You have wasted the whole term."

Indeed, speech errors show that features, segments, words, and phrases may be conceptualized well before they are uttered. This point is illustrated in the following examples of speech errors (the intended utterance is to the left of the arrow; the actual utterance, including the error, is to the right of the arrow):

1. The ***h***iring of minority faculty. → The ***f***iring of minority faculty. (The intended *h* is replaced by the *f* of *faculty*, which occurs later in the intended utterance.)
2. ***a***d h***o***c → ***o***dd h***a***ck (The vowels /æ of the first word and /a/ of the second are exchanged or reversed.)
3. ***b***ig and ***f***at → ***p***ig and ***v***at (The values of a single feature are switched: in *big* [+voiced] becomes [–voiced] and in *fat* [–voiced] becomes [+voiced].)
4. There are many ministers in our church. → There are many churches in our minister. (The root morphemes *minister* and *church* are exchanged; the grammatical plural morpheme remains in its intended place in the phrase structure.)
5. salute smartly → smart salutely (heard on *All Things Considered*, National Public Radio (NPR), May 17, 2007) (The root morphemes are exchanged, but the *-ly* affix remains in place.)
6. Seymour sliced the salami with a knife. → Seymour sliced a knife with the salami. (The entire noun phrases—article + noun—were exchanged.)

In these errors, the intonation contour (primary stressed syllables and variations in pitch) remained the same as in the intended utterances, even when the words were rearranged. In the intended utterance of (6), the highest pitch would be on *knife*. In the misordered sentence, the highest pitch occurred on the second syllable of *salami*. The pitch rise and increased loudness do not therefore depend on the individual words but are determined by the syntactic structure of the sentence.

These errors show us that syntactic structures exist independently of the words that occupy them, and intonation contours can be mapped onto those structures without being associated with particular words.

Errors like those just cited are constrained in interesting ways. Phonological errors involving segments or features, as in (1), (2), and (3), primarily occur in content words, and not in grammatical morphemes, showing the distinction between these lexical classes. In addition, free morphemes may be interchanged, bound morphemes may not be. We do not find errors like *The boying are sings* for *The boys are singing*. Typically, as example (4) illustrates, the affixes are left behind when root morphemes switch, and then attach to the moved morpheme. Errors like those in (1)–(6) show that speech production operates in real time using the features, segments, morphemes, words, and phrases that exist in the grammar. They also show that when we speak, words are chosen and sequenced ahead of when they are articulated. Planning also goes on at the sentence level. In experimentally controlled settings, speakers take longer to initiate (begin uttering) passive sentences like (1a) than active sentences like (1b). They also take longer to begin uttering subject–object relative clauses (underlined once) like (2a) than object–subject relative clauses (doubly underlined) like (2b).

(1) a. The ball was chased by Nellie.
b. Nellie chased the ball.

(2) a. <u>The cat that scratched the dog</u> climbed the tree.
b. <u>The cat that the dog chased</u> climbed the tree.

These findings suggest that more planning goes into sentences that have a less common word order than into sentences with subject–verb–object word order. Interestingly, however, speakers are more likely to produce a passive sentence after hearing a passive, despite its non-typical word order. In syntactic priming experiments, speakers are asked to describe a scene after hearing an unrelated active or passive sentence. Results show that they are more likely to describe the scene using a passive if that is what they have just heard. Researchers believe that once a particular structure has been built, it remains "active" in memory and facilitates the subsequent building of a similar structure.

Speakers must also combine simple sentences into complex structures containing embedded clauses, relative clauses, and so on. Studies of speakers' hesitations show that planning for complex structures happens at the beginning of clauses. For example, the initiation time is shorter for producing a simple NP subject such as (1):

1. The large and raging river . . .

than for a subject NP like (2):

2. The river that stopped flooding . . . ,

which contains a relative clause, even though both NPs are the same length (in terms of number of syllables).

Pauses occur more often at the beginning of clauses than within them, and speech errors involving exchanges of linguistic units, such as those in (4)–(6) above, happen within clauses and not across clause boundaries. These findings among others support the hypothesis that the clause boundary is the locus of planning in complex sentences, and that sentences are bundled into clause-size units before they are produced.

The comprehension and production of language is an enormously complex process that depends on many aspects of our linguistic knowledge, as well as dedicated processing principles and other cognitive capacities such as memory. Both normal conversational data and experimental data provide the psycholinguist with information about the different units, mechanisms, and stages speakers use to encode an idea into speech and listeners use to decode the speech signal into a linguistic message.

Brain and Language

How can you talk if you don't have a brain?

DOROTHY: FROM THE MOTION PICTURE *The Wizard of Oz*, 1939.

Attempts to understand the complexities of human cognitive abilities, especially language, are as old and as continuous as history itself. What is the nature of the brain? What is the nature of human language? And what is the relationship between the two? Philosophers and scientists have grappled with these kinds of questions over the centuries. But modern advances in brain technology have enabled researchers to study the brain-language connection in ways scarcely imagined in earlier times. The study of the biological and neural foundations of language is called **neurolinguistics**. Like psycholinguistics, neurolinguistics is largely an experimental science. Neurolinguistic research is often based on data from atypical or impaired language and uses such data to understand properties of human language in general.

The Human Brain

The human brain is unique in that it is the only container of which it can be said that the more you put into it, the more it will hold.

GLENN DOMAN

The brain is the most complex organ of the body. The surface of the brain is the **cortex**, often called "gray matter," consisting of 100 billion neurons (nerve cells) and even more glial cells (which support and protect the neurons and have as yet unknown other functions). The cortex is the decision-making organ of the body. It receives messages from all of the sensory organs, initiates all voluntary and involuntary actions, and is the storehouse of our memories and the seat of our consciousness. It is the organ that most distinguishes humans from other animals. It's where human language resides.

The brain is composed of a right and a left **cerebral hemisphere**, joined by the **corpus callosum**, a network of more than 200 million fibers (see Figure 10.2 below). The corpus callosum allows the two hemispheres of the brain to communicate with each other. Without this system of connections, the hemispheres would operate independently. In general, the left hemisphere controls the right side of the body, and the right hemisphere controls the left side. If you point with your right hand, the left hemisphere is responsible for your action. Similarly, sensory information from the right side of the body (e.g., right hand, right visual field) is received by the left hemisphere of the brain, and sensory input to the left side of the body is received by the right hemisphere. This is referred to as **contralateral** brain function. The following quote from the Bible suggests that the connection between control of the right side of the body and speech has been suspected for a long time.

If I forget thee, O Jerusalem, let my right hand forget her cunning.
If I do not remember thee, let my tongue cleave to the roof of my mouth;
Psalm 137, King James Version

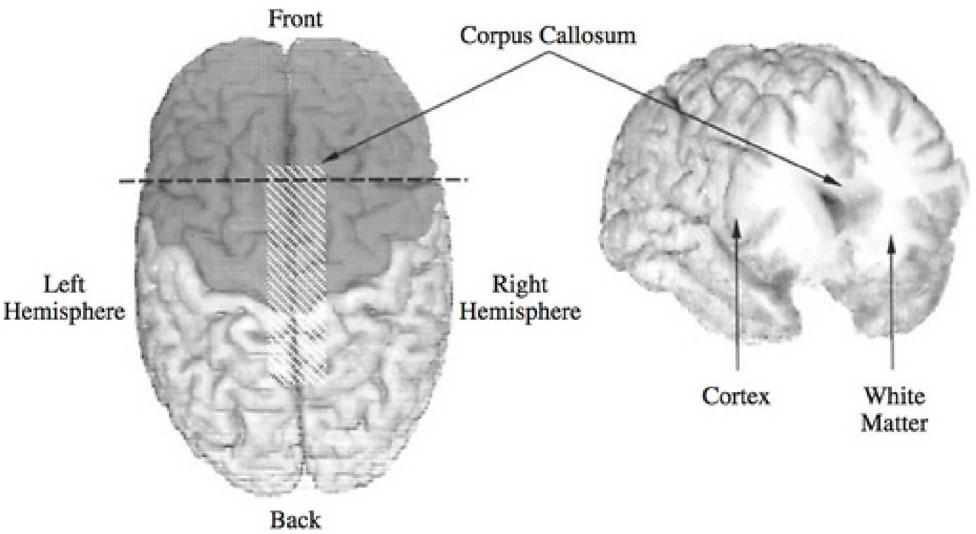
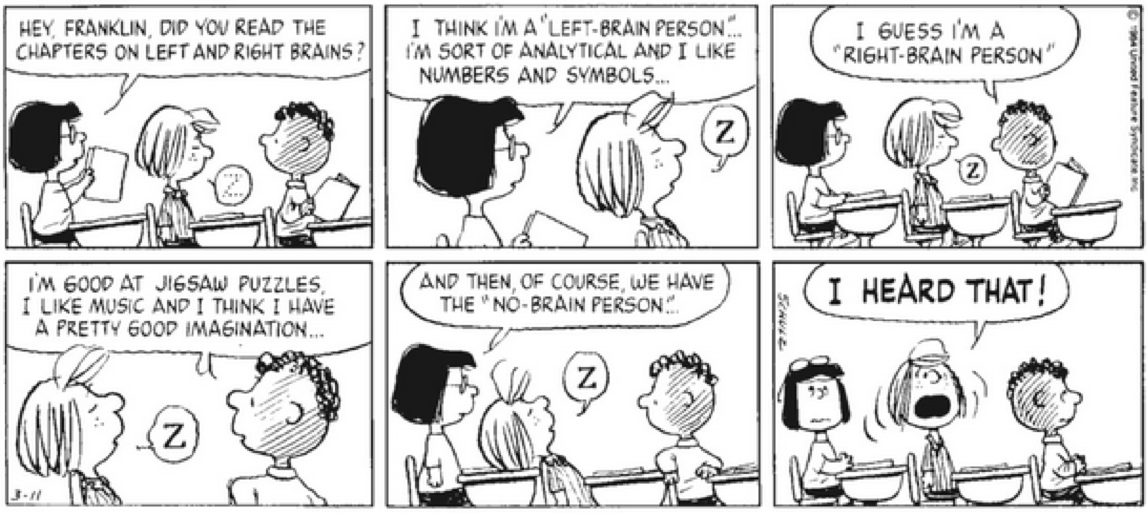


FIGURE 10.2 | Three-dimensional reconstruction of the normal living human brain. The images were obtained from magnetic resonance data using the Brainvox technique. *Left panel* = view from top. *Right panel* = view from the front following virtual coronal section at the level of the dashed line.
Courtesy of Hanna Damásio.

The Localization of Language in the Brain



An issue of central concern has been to determine which areas of the brain are responsible for human linguistic abilities. In the early nineteenth century, Franz Joseph Gall proposed the theory of **localization**, which is the idea that different human cognitive abilities and behaviors are localized in specific parts of the brain. In light of our current knowledge about the brain, some of Gall's particular views are amusing. For example, he proposed that language is located in the frontal lobes of the brain because as a young man he had noticed that the most articulate and intelligent of his fellow students had protruding eyes, which he believed reflected overdeveloped brain material. He also put forth a pseudoscientific theory called "organology" that later came to be known as **phrenology**, which is the practice of determining personality traits, intellectual capacities, and other matters by examining the "bumps" on the skull.

A disciple of Gall's, Johann Spurzheim, introduced phrenology to America, constructing elaborate maps and skull models such as the one shown in Figure 10.3 (on the next page) in which language is located directly under the eye. Phrenology has long been discarded as a scientific theory, but Gall's view that the brain is not an undifferentiated mass, and that linguistic and other cognitive capacities are functions of localized brain areas, has been upheld by scientific investigation of brain disorders, and, over the past three-and-a-half decades, by numerous studies using sophisticated technologies examining both normal and impaired brain function.

Aphasia

The study of **acquired aphasia** has been an important area of research in understanding the relationship between the brain and language. Aphasia is the neurological term for any language disorder that results from brain damage caused by disease or trauma.

In the second half of the nineteenth century, significant scientific advances were made in localizing language in the brain based on the study of people with aphasia. In the 1860s, the French surgeon Paul Broca proposed that language is

FIGURE 10.3 | Phrenology skull model.

localized in the left hemisphere of the brain, and more specifically in the front part of the left hemisphere (now called **Broca's area**). At a scientific meeting in Paris, he claimed that we speak with the left hemisphere. Broca's claim was based on a study of his patients who suffered language deficits after brain injury to the left frontal lobe.

A decade later, Carl Wernicke, a German neurologist, described another variety of aphasia that occurred in patients with lesions in areas of the left temporal lobe, now known as **Wernicke's area**. **Lateralization** is the term used to refer to the localization of function to one hemisphere of the brain. Language is lateralized to the left hemisphere, and the left hemisphere appears to be the language hemisphere from infancy on. Figure 10.4 (on the next page) is a view of the left side of the brain that shows Broca's and Wernicke's areas.

The Linguistic Characterization of Aphasic Syndromes

Most aphasics do not show total language loss. Rather, different aspects of language are selectively impaired, and the kind of impairment is generally related to the location of the brain damage. Because of this damage-deficit correlation, research on patients with aphasia has provided a great deal of information about how language is organized in the brain.

Patients with injuries to Broca's area may have **Broca's aphasia**, as it is often called today. Broca's aphasia is characterized by labored speech and certain kinds of word-finding difficulties, but it is primarily a disorder that

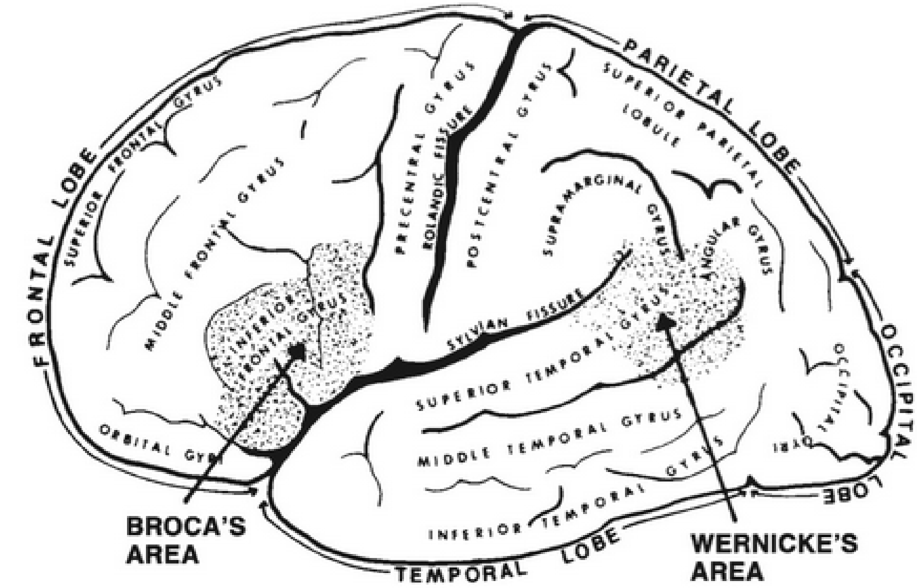


FIGURE 10.4 | Lateral *(external)* view of the left hemisphere of the human brain, showing the position of Broca's and Wernicke's areas—two key areas of the cortex related to language processing.

affects a person's ability to form sentences with the rules of syntax. One of the most notable characteristics of Broca's aphasia is that the language produced is often **agrammatic**, meaning that it frequently lacks articles, prepositions, pronouns, auxiliary verbs, and other function words. Broca's aphasics also typically omit inflections such as the past tense suffix *-ed* or the third person singular verb ending *-s*. Here is an excerpt of a conversation between a patient with Broca's aphasia and a doctor:

DOCTOR: Could you tell me what you have been doing in the hospital?
PATIENT: Yes, sure. Me go, er, uh, P.T. [physical therapy] none o'cot, speech . . . two times . . . read . . . r . . . ripe . . . rike . . . uh write . . . practice . . . get . . . ting . . . better.
DOCTOR: And have you been going home on weekends?
PATIENT: Why, yes . . . Thursday uh . . . uh . . . uh . . . no . . . Friday . . . Bar . . . ba . . . ra . . . wife . . . and oh car . . . drive . . . purpike . . . you know . . . rest . . . and TV.

Broca's aphasics (also often called **agrammatic aphasics**) may also have difficulty understanding sentences that have non-canonical word order due to the application of movement rules. They are far better at understanding a subject *wh* question like:

Which girl kissed the boy?

which adheres to S–V–O (girl-kiss-boy) word order, than an object *wh* question such as:

Which girl did the boy kiss?

which disrupts canonical word order (girl-boy-kiss). Similarly, they will understand sentences with a subject relative clause (in brackets) such as:

The girl [who is drawing the boy] is wearing a hat.

where S–V–O (girl-draw-boy) order is preserved more reliably than sentences with an object relative clause such as:

The girl [who the boy is drawing] is wearing a hat.

where the object (*the girl*) is displaced resulting in non-canonical order. They have trouble with passives sentences for the same reason. In a passive sentence such as:

The cat was chased by the dog.

the subject (*the cat*) is the logical object of the verb (*chase*) and the NP in the *by*-phrase (*the dog*) is the logical subject.

Agrammatic aphasics will have less difficulty understanding "transformed" sentences:

Which book did the boy read?

or

The car was chased by the dog.

where they can figure out who did what to whom based on nonlinguistic knowledge.

It's implausible for books to read boys or for cars to chase dogs, and aphasic people can use that knowledge to interpret the sentence. Unlike Broca's patients, people with **Wernicke's aphasia** produce fluent speech with good intonation, and they may largely adhere to the rules of syntax. However, their language is often semantically incoherent. For example, one patient replied to a question about his health with:

I felt worse because I can no longer keep in mind from the mind of the minds to keep me from mind and up to the ear which can be to find among ourselves.

Another patient described a fork as "a need for a schedule" and another, when asked about his poor vision, replied, "My wires don't hire right."

People with damage to Wernicke's area have difficulty naming objects presented to them and in choosing words in spontaneous speech. They may make numerous lexical errors (word substitutions), often producing **jargon** and **nonsense words**, as in the following example:

The only thing that I can say again is madder or modder fish sudden fishing sewed into the accident to miss in the purdles.

Another example is from a patient who was a physician before his aphasia. When asked whether he was a doctor, he replied:

Me? Yes sir. I'm a male demaploze on my own. I still know my tubaboys what for I have that's gone hell and some of them go.

The linguistic deficits exhibited by people with Broca's and Wernicke's aphasias point to a **modular** organization of language in the brain. Damage to different parts of the brain results in different kinds of linguistic impairment (e.g., syntactic versus semantic). This supports the hypothesis that the mental grammar, like the brain itself, is not an undifferentiated system, but rather consists of distinct components or modules. The kind of word substitutions that aphasic patients produce also tell us about how words are organized in the mental lexicon. Sometimes the substituted words are similar to the intended words in their sounds. For example, *pool* might be substituted for *tool*, *sable* for *table*, or *crucial* for *crucible*. Sometimes they are similar in meaning (e.g., *table* for *chair* or *boy* for *girl*). These errors resemble the speech errors that unimpaired speakers might make, but they occur far more frequently in people with aphasia. The substitution of semantically or phonetically related words tells us that neural connections exist among semantically related words and among words that sound alike. Words are not mentally represented in a simple list but rather in an organized network of connections, comprising lexical neighborhoods.

Most of us have experienced word-finding difficulties in speaking if not in reading, as Alice did in "Wonderland" when she said:

> "And now, who am I? I will remember, if I can. I'm determined to do it!" But being determined didn't help her much, and all she could say, after a great deal of puzzling, was "L, I know it begins with L."

This **tip-of-the-tongue phenomenon** is not uncommon. Aphasics who suffer from **anomia (anomic aphasia)** have constant word-finding difficulties.

Deaf signers with damage to the left hemisphere show aphasia for sign language similar to the language breakdown in hearing aphasics, even though sign language is a visual-spatial language, and the right hemisphere is the one specialized for most aspects of visual and spatial cognition. Moreover, in tests measuring hemispheric activation (some of which we discuss below), one finds that it is the *auditory* cortex in the left hemisphere of deaf individuals attempting to process signs that is activated—the very area we might expect to be the *least* responsive to language in the deaf.

Deaf patients with lesions in Broca's area show language deficits like those found in hearing patients, namely, severely dysfluent, agrammatic sign production. Likewise, those with damage to Wernicke's area have fluent but often semantically incoherent sign language, filled with made-up signs. Although deaf aphasic patients show marked sign language deficits, they have no difficulty producing nonlinguistic gestures or sequences of nonlinguistic gestures, even though both nonlinguistic gestures and linguistic signs are produced by the same "articulators"—the hands and arms. Deaf aphasics also have no difficulty in processing nonlinguistic visual-spatial relationships, just as hearing aphasics have no problem with processing nonlinguistic auditory stimuli.

The language difficulties suffered by aphasics are not caused by any general cognitive or intellectual impairment or loss of motor or sensory control. of the speech organs or hearing apparatus. Aphasics can produce and hear sounds and their other cognitive abilities may be intact. Whatever loss they suffer has to do only with the language faculty (or specific parts of it).

In addition to the evidence provided by deaf aphasics there is also considerable experimental evidence showing that sign language grammar—like spoken language grammar—resides in the left hemisphere. These findings are important because they show that the left hemisphere is lateralized for language—an abstract system of symbols and rules—and not simply for hearing or speech. Language can be realized in different modalities, spoken or signed, but is organized in the brain in the same way regardless of modality.

The kind of selective impairments that we find in people with aphasia has provided important information about the organization of language and other cognitive abilities in the brain, especially grammar and the lexicon. It tells us that language is a separate cognitive module—so aphasics can be otherwise cognitively normal—and that within language, separate components can be differentially affected by damage to different regions of the brain.

Acquired Dyslexia

Evidence concerning the organization of the lexicon and how we access it is also provided by people with **acquired dyslexia**, a disorder in which reading ability is disrupted due to brain damage to the left hemisphere. Two types of acquired dyslexia have been identified, each with different effects.

People with *deep dyslexia* make many word substitutions such as the following:

Stimulus	Response 1	Response 2
act	*play*	*play*
applaud	*laugh*	*cheers*
example	*answer*	*sum*
heal	*pain*	*medicine*
south	*west*	*east*

The patient was unable to read the stimulus word presented on a card, though his responses were semantically related to the target, indicating that he was able to get to the correct lexical neighborhood but retrieved the wrong item.

People with deep dyslexia also have particular difficulty reading function words such as prepositions, conjunctions, and auxiliaries. The patient who produced the semantic substitutions cited previously was not able to read function words at all. When presented with words such as *which* or *would*, he just said, "No" or "I hate those little words." However, he could read phonetically identical nouns and verbs, though with many semantic mistakes, as shown in the following:

Stimulus	Response	Stimulus	Response
witch	*witch*	which	*no!*
hour	*time*	our	*no!*
eye	*eyes*	I	*no!*
hymn	*bible*	him	*no!*
wood	*wood*	would	*no!*

These errors, like those of people with agrammatic aphasia, provide evidence that content words and function words are processed in different brain areas or by different neural mechanisms, further supporting the view that both the brain and language are structured in a complex, modular fashion.

Fluent readers can access a familiar word in the mental lexicon just by seeing it, without sounding it out. People with *surface dyslexia* cannot do this. They must "sound out" every word, just like a beginning reader or an adult encountering a new word. This makes reading difficult and laborious and makes many words unreadable in a language like English with a very opaque spelling system. Like aphasia, deep dyslexia and surface dyslexia provide information about the lateralization of the mental lexicon to the left hemisphere and about its nature, organization, and access routes.

Japanese readers provide additional evidence regarding hemispheric specialization. The Japanese language has two main writing systems. One system, *kana*, is based on the sound system of the language; each symbol corresponds to a syllable. The other system, *kanji*, is ideographic; each symbol corresponds to a word. (Writing systems are discussed in Chapter 8.) *Kanji* is not based on the sounds of the language. Japanese speakers with left-hemisphere damage are impaired in their ability to read the phonetically based *kana*, whereas ones with right-hemisphere damage are impaired in their ability to read the ideographic *kanji* symbols. In addition, experiments with unimpaired Japanese readers show that the right hemisphere is better and faster than the left hemisphere at reading *kanji*, and conversely, the left hemisphere does better with *kana*, though the left hemisphere can read both systems.

Brain Imaging in Aphasic Patients

Today we no longer need to rely on surgery or autopsy to locate brain lesions. Noninvasive neuroimaging technologies such as computer tomography (CT) scans and **magnetic resonance imaging (MRI)** can reveal lesions in the living brain shortly after the damage occurs. In addition, **functional positron emission tomography (fPET)** scans and **functional MRI (fMRI)** scans can reveal the brain in action by measuring blood flow and oxygen utilization in different areas of the brain during the performance of various linguistic and other cognitive tasks. It is now possible to detect changes in brain activity and to relate these changes to localized brain damage and specific linguistic and nonlinguistic cognitive tasks.

Figures 10.5 and 10.6 show MRI scans of the brains of a Broca's aphasic patient and a Wernicke's aphasic patient. The black areas show the sites of the lesions. Each diagram represents a slice of the left side of the brain.

Dramatic evidence for a differentiated and structured brain is also provided by studies of patients with lesions in regions of the brain other than Broca's and Wernicke's areas. Some patients have difficulty speaking a person's name; others have problems naming animals; and still others cannot name tools. fMRI studies have revealed the shape and location of the brain lesions in each of these types of patients. The patients in each group had brain lesions in distinct, nonoverlapping regions of the left temporal lobe. In an associated PET scan study, normal subjects were asked to name persons, animals, or tools. Experimenters found

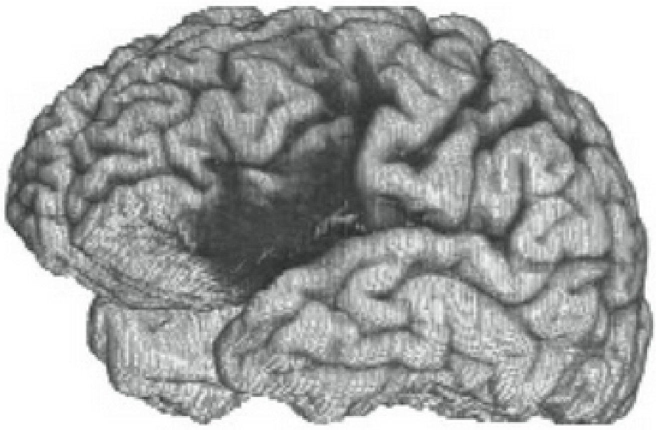


FIGURE 10.5 | Three-dimensional reconstruction of the brain of a living patient with Broca's aphasia. Note area of damage in left frontal region (*dark gray*), which was caused by a stroke.
Courtesy of Hanna Damásio.

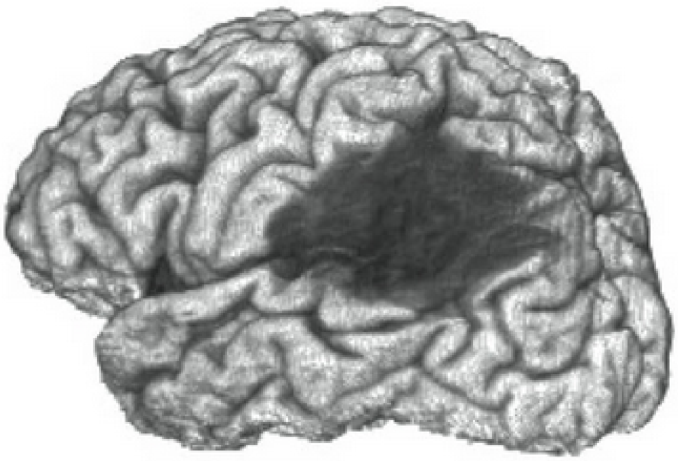


FIGURE 10.6 | Three-dimensional reconstruction of the brain of a living patient with Wernicke's aphasia. Note area of damage in left posterior temporal and lower parietal region (*dark gray*), which was caused by a stroke.
Courtesy of Hanna Damásio.

that in the normal brains there was differential activation in just those sites that were damaged in the aphasics Similarly, some brain-damaged patients lose the ability to recognize sounds or colors or familiar faces while retaining all other functions. A patient may not be able to recognize his wife when she walks into the room until she starts to talk. This suggests the separability of many aspects of visual and auditory processing.

Other sources of evidence concerning the functional differences between the left and right hemispheres is provided by individuals who have suffered trauma to the brain or have undergone brain surgery for certain medical conditions. For example, a member of the U.S. Congress was shot in the head in an assassination attempt in 2011, with the bullet passing through the left hemisphere of the brain. After a year of courageous recovery, news reports made clear that her linguistic ability was still severely compromised and TV images distinctly revealed an asymmetric weakness to the right side of the body.

Split Brains

It takes only one hemisphere to have a mind.

A. L. WIGAN, *The Duality of the Mind*, 1844

An extreme measure used to help people suffering from intractable epilepsy is a procedure in which a surgeon severs the corpus callosum (see Figure 10.2), the fibrous network that connects the two halves. When this pathway is severed, there is no communication between the "two brains," making it possible to test the functions of each (now isolated) hemisphere without interference from the other.

In people who have undergone **such split-brain** surgery, the two hemispheres appear to be independent, and messages sent to the brain result in different responses, depending on which side receives the message. For example, if a pencil is placed in the left hand of a split-brain person whose eyes are closed, the person can use the pencil appropriately but cannot name it because only the left hemisphere can speak. The right brain senses the pencil but the information cannot be relayed to the left brain for linguistic naming because the connections between the two halves have been severed. By contrast, if the pencil is placed in the right hand, the subject is immediately able to name it as well as to describe it because the sensory information from the right hand goes directly to the left hemisphere, where the language areas are located.

Studies of split-brain patients have also shown that when the interhemispheric visual connections are severed, visual information from the right and left visual fields becomes confined to the left and right hemispheres, respectively. Because of the crucial endowment of the left hemisphere for language, written material delivered to the right hemisphere cannot be read aloud if the brain is split, because the information cannot be transferred to the left hemisphere. Thus, an image or picture that is flashed to the right visual field of a split-brain patient (and therefore processed by the left hemisphere) can be named. However, when the picture is flashed in the left visual field and therefore "lands" in the right hemisphere, it cannot be named. It is only under special, experimental circumstances that independent functions of the hemispheres are revealed. Under normal living circumstances both hemispheres have access to whatever a person sees or hears.

Experiments of this sort have provided information on the different capabilities of the two hemispheres. The right brain does better than the left in pattern-matching tasks, in recognizing faces, and in spatial tasks. The left hemisphere is superior for language, rhythmic perception, temporal-order judgments, and arithmetic calculations. According to the psychologist Michael Gazzaniga, "the right hemisphere as well as the left hemisphere can emote and while the left can tell you why, the right cannot."

Neural Evidence of Grammatical Phenomena

The human brain is a most unusual instrument of elegant and as yet unknown capacity.

STUART SEATON

Thanks to the invention of imaging and other technologies, much can be learned about the lateralization of language and other cognitive functions from looking at healthy brains. Experimental tests of unimpaired people are used to map the brain and to investigate the independence of different aspects of language as well as the independence of language from other cognitive systems.

In addition to fMRI and fPET discussed earlier, other widely used techniques include *Event-related potentials (ERPs* and *Magnetoencephalography (MEG)*. **Event-related potentials (ERPs)** are the electrical signals emitted from the brain in response to different linguistic stimuli and can be monitored through electrodes taped to different areas of the skull. This technique, based upon EEG (electroencephalogram) readings, exploits the fact that the brain is electrically active and that this electrical activity can be measured both for its strength (amplitude) and for its pattern of responses over time.

Magnetoencephalography (MEG) records small changes in the brain's magnetic fields and provides information on which parts of the brain are involved in particular language-related tasks. Like ERPs, MEG provides information about how the brain reacts over time.

These noninvasive methods can also reveal how the healthy brain reacts to particular linguistic stimuli. For example, how the normal brain responds in deciding whether two or more sounds are the same or different, whether a sequence of sounds constitutes a real or possible word, or whether a sequence of words forms a grammatical or ungrammatical sentence. The results of these studies reaffirm earlier findings that language resides in specific areas of the left hemisphere, and demonstrate the neurological reflexes of many of the linguistic categories and constraints posited by linguists.

Neurolinguistic Studies of Speech Sounds

These new techniques have provided many insights into how the human brain responds to sounds. A first important finding is that the brain reacts differently to speech versus non-speech sounds. ERP responses are greater from the left hemisphere when the subject hears speech sounds.

Many studies also provide neurolinguistic evidence for the categories and concepts that linguists postulate in their descriptions of sound systems. Experiments using ERPs and MEGs have shown a neural reflex of categorical perception: The brain reacts differently to sounds that are phonemically different (e.g., [t] and [k]) than to sounds that are acoustically distinct (e.g., [p] and [p^h]) but non-phonemic. The overall patterns of response to phonemes versus allophones differ in intensity, speed, and location in the brain. An fMRI experiment involving French and Japanese speakers has demonstrated distinct response patterns for phonotactically permissible versus impermissible sequences of sounds in their language as well as faster reaction times to the phonotactically correct sequences. Similar results have been found in studies of deaf signers who show different neurological responses to phonotactically permissible and impermissible hand configurations in sign language.

Neurolinguistic Studies of Sentence and Word Structure

Modern technologies have also been used to examine the brain's response to the syntactic patterns of language. ERP experiments show variations in timing, pattern, amplitude, and hemisphere of response when subjects hear sentences that are meaningless, such as:

The man admired Don's headache of the landscape.

as opposed to meaningful sentences such as:

The man admired Don's sketch of the landscape.

Even Jabberwocky sentences—sentences that are grammatical but contain nonsense words, such as Lewis Carroll's *'Twas brillig, and the slithy toves* elicit an asymmetrical left-hemisphere ERP response, demonstrating that the left hemisphere is sensitive to grammatical structure even in the absence of meaning. Such findings provide neurological evidence for the separation between syntax and semantics posited by linguists. Moreover, because ERPs also show the timing of neuronal activity as the brain processes language, they provide insight into the mechanisms that allow the brain to process language quickly and efficiently, on the scale of milliseconds.

Another set of studies has examined brain responses to syntactic dependencies of the sort shown in *wh* questions (see Chapter 2). Subjects hear sentences in which the underlying subject or object has been moved to the beginning of the sentence. In the case of a moved subject in example (1), the movement is shorter and the basic word order is kept:

(1) Who . . ___ left the room?

On the other hand, movement from object position as in example (2) involves a longer distance between the moved element *(which bagel)* which psycholinguists call the "filler," and the position from which it moves, referred to as the "gap".

(2) Which bagel did Seymour slice ___?

Various studies show that sentences with moved objects elicit longer response times than sentences with moved subjects, providing neural correlates of different *wh* movements (as discussed in Chapter 2).

Many neurolinguistic studies have examined the brain's response to ungrammatical sentences, manifested by a type of ERP pattern called a MisMatch Negativity (MMN). These experiments find that different types of ungrammatical sentences evoke distinct waveforms. Thus, violations of phrase structure, C-selection, agreement rules, among others produce a specific neural "signature."

Interestingly, the brain responds at once to morphosyntactic violations (e.g., **a boys is running*) and does so outside the scope of attention. In one study, subjects were divided into three groups: One group simply listened to grammatical and ungrammatical phrases; another watched a video while listening to the same phrases; and a third performed a complex auditory task while listening to the phrases. An MMN response to the syntactic violations was almost immediate, within the first 100–200 milliseconds after hearing the phrase, and the response was equally rapid and strong whether or not the listeners had to perform another task. Particularly striking was the response of those subjects who had to do the auditory task. They had the same strong MMN response, showing that even a complex task requiring considerable attention *in the same auditory modality* did not compete with syntactic processing. The results of this study demonstrate that syntactic processing is like a reflex, in being both automatic and attention-free.

Recent studies have also used fMRI to examine brain activation for past tense, present tense and agreement morphology. The results showed different neural signatures for the different inflectional morphemes, and was also distinct from the neural reflex of processing bare verb stems.

Experimental evidence from these various neurolinguistic experiments has provided considerable insight into how the brain processes language, and has also lent empirical support to many of the abstract categories, rules, concepts, and components of grammar.

Language and Brain Development

If the brain were so simple we could understand it, we would be so simple we couldn't.

LYALL WATSON

Numerous neurolinguistic studies have found that the way the brain is organized for language and grammar in the adult is already reflected in the brains of newborns and young infants. Lateralization of language to the left hemisphere is a process that begins very early in life, even before language actively develops. For example, Wernicke's area is visibly distinctive in the left hemisphere of the fetus by the twenty-sixth gestational week. Moreover, infants show evidence of many of the neural correlates of linguistic categories that we observe in adults.

Left Hemisphere Lateralization for Language in Young Children

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Everyone loves a smiling baby, but babies' smiles do more than light up a room. They reveal something very important about how the developing brain is organized for language.

In a very intriguing study, researchers videotaped smiling babies and babbling babies (producing syllabic sequences like *mamama* or *gugugu*) between the ages of five and twelve months. The videotapes showed that when the babies were smiling their mouths were opened wider on the left side (the side controlled by the right hemisphere) whereas when they babbled the *right* side of their mouths (controlled by the left hemisphere) were opened wider, indicating greater left hemisphere involvement for language even during the babbling period (see Chapter 9).

Many other studies of infants and young children support this conclusion. For example, infants as young as one week old show a greater electrical response in the left hemisphere to language and in the right hemisphere to music, similar to adults. A study measuring brain activation in awake and sleeping three-month-old infants when hearing forward and backward speech showed that different areas of the cortex responded in the two cases.

We noted in previous chapters, that behavioral tests show that infants—like adults—perceive speech sounds categorically. ERP studies have found neurological correlates of categorical perception in infants, just as for adults. These studies show that the infant brain responds differently, and with the same pattern and speed as found in adults, to *phonemic* categories than to non-phonemic acoustic distinctions. This neural pattern occurs even in sleeping babies, showing that the response is automatic and does not require the attention of the infant.

These and similar experiments show that from birth onward, the left hemisphere differentiates between nonlinguistic acoustic processing and the linguistic processing of sounds, and uses the same neural pathways as adults. Other studies indicate the same holds true for syntax. Very young children seem to process syntactic structures in the same area of the brain and with the same neurological indices as adults, albeit slightly more slowly. In one study, two-year-olds listened to grammatical and ungrammatical sentences. Some of the ungrammatical sentences had nouns where verbs should be, and some had verbs in noun positions. The toddlers showed a clear left-lateralized response to the ungrammatical sentences and even different patterns for the noun versus verb substitutions.

Brain Plasticity

While the left hemisphere is innately predisposed to specialize for language, there is also evidence of considerable *plasticity* (i.e., flexibility) in the system during the early stages of language development. This means that under certain circumstances, the right hemisphere can take over many of the language functions that would normally reside in the left hemisphere.

An impressive illustration of plasticity is provided by children who have undergone a procedure known as **hemispherectomy**, in which one hemisphere of the brain is surgically removed. This procedure is used to treat otherwise intractable cases of epilepsy. In cases of left hemispherectomy after language acquisition has begun, children experience an initial period of aphasia. However, in certain cases, depending on the underlying disease that led to the epilepsy, the child may reacquire a linguistic system that is virtually indistinguishable from that of normal children. They also show many of the developmental patterns of normal language acquisition. UCLA researchers who have studied many of these children hypothesize that the latent linguistic ability of the right hemisphere is "freed" by the removal of the diseased left hemisphere, which may have had a strong inhibitory effect before the surgery.

In adults, however, surgical removal of the left hemisphere inevitably results in severe loss of language function (and so is done only in life-threatening circumstances), whereas adults (and children who have already acquired language) who have had their right hemispheres removed generally retain their language abilities. Other cognitive losses may result, such as those typically lateralized to the right hemisphere. The plasticity of the brain decreases with age and with the increasing specialization of the different hemispheres and regions of the brain.

Despite strong evidence that the left hemisphere is predetermined to be the language hemisphere in most humans, some studies suggest that the right hemisphere also plays a role, especially in the earliest stages of language acquisition. Children with prenatal, perinatal, or childhood brain lesions in the right hemisphere can show delays and impairments in babbling and vocabulary learning, whereas children with early left hemisphere lesions demonstrate impairments in their ability to form phrases and sentences. In addition, many children who undergo right hemispherectomy before two years of age do not develop language, even though they still have a left hemisphere.

Various findings converge to show that the human brain is essentially designed to specialize for language in the left hemisphere but that the right hemisphere is involved in early language development. They also show that the brain is remarkably resilient and that if left brain trauma occurs early in life, its normal functions can be taken over by the right hemisphere.

The Critical Period

Under ordinary circumstances a child is introduced to language virtually at the moment of birth. Adults talk to him and to each other in his presence. Children do not require explicit language instruction, but they do need exposure to language to develop normally. Children who do not receive linguistic input during their formative years do not achieve native-like grammatical competence. Moreover, behavioral tests and brain imaging studies show that late exposure to language alters the fundamental organization of the brain for language.

The **critical-age hypothesis** asserts that language is biologically based and that the ability to learn a native language develops within a fixed period, from birth to middle childhood. During this **critical period**, language acquisition proceeds easily, swiftly, and without external intervention. After this period, the acquisition of grammar is difficult and, for most individuals, never fully achieved. Children deprived of language during this critical period show atypical patterns of brain lateralization.

Many species have a critical period for specific, biologically triggered behaviors. For example, during the period from nine to twenty-one hours after hatching, ducklings will follow the first moving object they see, whether or not it looks, quacks, and waddles like a duck. Such behavior is not the result of a conscious decision, external teaching, or intensive practice. It unfolds according to what appears to be a maturationally determined schedule that is universal across the species. Similarly, as discussed in Chapter 1, certain species of birds develop their bird song within a biologically determined window of time.

Instances of children reared in environments of extreme social isolation constitute "experiments in nature" for testing the critical-age hypothesis. The most dramatic cases are those described as "wild" or "feral" children. A celebrated case, documented in Francois Truffaut's film *The Wild Child,* is that of Victor, "the wild boy of Aveyron," who was found in 1798. It was ascertained that he had been left in the woods when very young and had somehow survived. In 1920, two children, Amala and Kamala, were found in India, supposedly having been reared by wolves.

Other children have been deliberately isolated from normal social interaction and language. In 1970, a child called Genie in the scientific reports was discovered. She had been confined to a small room under conditions of physical restraint and had received only minimal human contact from the age of eighteen months until nearly fourteen years.

Regardless of the cause of the isolation, none of these children was able to speak or knew any language at the time they were reintroduced into society. This linguistic inability could be simply explained by the fact that these children received no linguistic input, showing that language acquisition, though an innate, neurologically-based ability, must be triggered by input from the environment. In the documented cases of Victor and Genie, however, these children were unable to acquire grammar even after years of exposure, and despite the ability to learn many words.

Genie was able to learn a large vocabulary, including words for colors, shapes, objects, natural categories, and abstract as well as concrete terms, but her grammatical skills never fully developed. The UCLA linguist Susan Curtiss, who worked with Genie for several years, reported that Genie's utterances were, for the most part, "the stringing together of content words, often with rich and clear meaning, but with little grammatical structure." Many utterances produced by Genie at the age of fifteen and later are like those of two-year-old children, and not unlike utterances of Broca's aphasia patients, or people with Specific Language Impairment (SLI, discussed below). Some such utterances are:

Man motorcycle have.
Genie full stomach.
Genie bad cold live father house.
Want Curtiss play piano.
Open door key.

Genie's utterances lacked articles, auxiliary verbs like *will* or *can*, the third-person singular agreement marker *-s*, the past-tense marker *-ed*, question words like *who, what,* and *where,* and pronouns. She had no ability to form more complex types of sentences such as questions (e.g., *Are you feeling hungry?)*. Genie started learning language after the critical period and was therefore never able to fully acquire the grammatical rules of English.

Tests of lateralization (ERP experiments and others) showed that Genie's language was lateralized to the *right* hemisphere. Her test performance was similar to that found in split-brain and left hemispherectomy patients, yet Genie was not brain damaged. Curtiss speculates that after the critical period, the usual language areas functionally atrophy because of inadequate linguistic stimulation. Genie's case also demonstrates that language is not the same as communication, because Genie was a powerful nonverbal communicator, despite her limited ability to acquire grammar.

Chelsea, another case of linguistic isolation, is a woman whose situation also reflects the critical-age hypothesis. She was born deaf but was wrongly diagnosed as intellectually disabled. When she was thirty-one, her deafness was finally diagnosed and she was fitted with hearing aids. She has received extensive language training and therapy for years and has acquired a large vocabulary. She can even invent new words when she doesn't have a word for something in her lexicon (e.g. *doctor tie* for *stethoscope*).

Like Genie, Chelsea readily learned new words, but she was even more impaired than Genie in the ability to develop grammar. While Genie developed some grammatical knowledge, such as the ability to distinguish transitive and intransitive verbs, Chelsea developed no knowledge of grammar at all. ERP studies of Chelsea's brain have revealed an equal response to language in both hemispheres. In other words, like Genie, Chelsea also fails to show the normal asymmetric brain organization for language.

More than 90 percent of children who are born deaf or become deaf before they have acquired language are born to hearing parents. These children also provide information about the critical age for language acquisition. Most parents of deaf children do not know sign language at the time their children are born, and hence most deaf children receive delayed language exposure. Several studies have investigated the acquisition of American Sign Language (ASL) among deaf signers exposed to the language at different ages. Early learners who received ASL input from birth and up to six years of age did much better in the production and comprehension of complex signs and sign sentences than late learners who were not exposed to ASL until after the age of twelve, even though all of the subjects at the time of these studies had used sign for more than twenty years. There was little difference; however, in vocabulary or knowledge of word order.

In a study comparing lateralization patterns in adult native speakers of English, adult native signers, and deaf adults who had not been exposed to sign language, the nonsigning deaf adults did not show the same cerebral asymmetries as either the hearing adults or the deaf signers. In recent years, there have been numerous studies of late learners of sign language, all with similar results.

A recent study reports that only deaf children whose hearing was successfully remediated (either by cochlear implants or hearing aids) by the age of eight months went on to develop rich grammars. This finding suggests the developmental "window of opportunity" for acquiring complex syntax may be far smaller than previously thought.

The cases of Genie and other isolated individuals, as well as deaf learners of ASL show that children cannot fully acquire language unless they are exposed to it within a biologically determined window of opportunity. This critical period is linked to brain lateralization. The human brain is primed to develop language in specific areas of the left hemisphere, but the normal process of brain specialization depends on early and systematic experience with language. Language acquisition plays a critical role in, and may even be *the* trigger for, the realization of normal cerebral lateralization for higher cognitive functions in general, not just for language.

Beyond the critical period, the human brain seems markedly impaired in the ability to acquire the grammatical aspects of language, even with substantial linguistic training or many years of exposure. However, it is possible to acquire words and various conversational skills after this point. This evidence suggests that the critical period for first language holds for the acquisition of grammatical abilities, but not necessarily for all aspects of language. The selectivity in acquisition that occurs beyond the critical period, like the selective impairment that occurs in various language disorders, points to a strongly compartmentalized language faculty. Language is separate from other cognitive systems and is itself a complex system with various components.

The Modular Mind: Dissociations of Language and Cognition

> [T]he human mind is not an unstructured entity but consists of components which can be distinguished by their functional properties.
>
> NEIL SMITH AND IANTHI-MARIA TSIMPLI, *The Mind of a Savant: Language, Learning, and Modularity*, 1995

The modular view of cognition is also supported by various case studies of extraordinary individuals who show deficits in certain cognitive domains alongside normal or superior abilities in other areas. The individuals we discuss below show *dissociations* between their linguistic abilities and other nonlinguistic cognitive abilities. In some cases, their language abilities far outpace the other areas, and in other cases, the reverse is true.

Linguistic Savants

There are numerous cases of intellectually handicapped individuals who, despite their disabilities in certain spheres, show remarkable talents in others. Such people are referred to as **savants**. Some of the most famous savants are human calculators, who can perform arithmetic computations at phenomenal speed, or calendrical calculators, who can tell you without pause on which day of the week any date in the last or next century falls.

Until recently, most such savants have been reported to be linguistically handicapped. They may be good mimics who can parrot speech, but they show meager creative language ability. But there are also cases of language savants, people who have acquired the highly complex grammar of their language (as well as other languages in some cases) but who lack nonlinguistic abilities of equal complexity. Laura and Christopher are two such cases.

Laura was a severely cognitively impaired young woman with a nonverbal IQ of 41 to 44. She lacked almost all number concepts, including basic counting principles, and could draw only at a preschool level. She had an auditory memory span limited to three units. Yet, when at the age of sixteen she was asked to name some fruits, she responded with *pears, apples,* and *pomegranates.* In this same period, she produced syntactically complex sentences such as *He was saying that I lost my battery-powered watch that I loved*, and *She does paintings, this really good friend of the kids who I went to school with and really loved*, and *I was like 15 or 19 when I started moving out of home. . . .*

Laura could not add 2 + 2. She didn't know how old she was or whether 15 is before or after 19. Nevertheless, Laura produced complex sentences with multiple phrases and embedded sentences. She used and understood passive sentences, and she was able to inflect verbs for number and person to agree with the subject of a sentence. She formed past tenses in accord with adverbs that referred to past time. She could do all this and more, but she could neither read nor write nor tell time. She did not know who the president of the United States was or what country she lived in. Her drawings of humans resembled potatoes with stick arms and legs. Yet, in a sentence imitation task, she both detected and corrected grammatical errors.

Laura is but one of the many examples of children who display well-developed grammatical abilities, less-developed abilities to associate linguistic expressions with the objects they refer to, and severe deficits in nonlinguistic cognition.

Another linguistic savant, Christopher, has a nonverbal IQ between 60 and 70. He lives in an institution because he is unable to take care of himself. The tasks of buttoning a shirt, cutting his fingernails, or vacuuming the carpet are too difficult for him. However, his linguistic competence is as rich and as sophisticated as that of any native speaker. Furthermore, when given written texts in some fifteen to twenty languages, he translates them quickly, with few errors, into English. The languages include Germanic languages such as Danish, Dutch, and German; Romance languages such as French, Italian, Portuguese, and Spanish; as well as Polish, Finnish, Greek, Hindi, Turkish, and Welsh. He learned these languages from speakers who used them in his presence, or from grammar books. Christopher loves to study and learn languages. Little else is of interest to him. His situation strongly suggests that his linguistic ability is independent of his general intellectual ability.

The question as to whether the language faculty is a separate cognitive system or whether it is derivative of more general cognitive mechanisms is controversial and has received much attention and debate among linguists, psychologists, neuropsychologists, and cognitive scientists. Cases such as Laura and Christopher argue against the view that linguistic ability derives from general intelligence because these two individuals (and others like them) developed language despite pervasive intellectual deficits. A growing body of evidence supports the view that the biologically determined human language faculty is highly specific and does not derive from general human intellectual ability.

Specific Language Impairment

People like Laura and Christopher have normal or superior linguistic skills though their abilities in other areas are very limited. There are also individuals who show the opposite profile: Among these are children with **Specific Language Impairment (SLI)**.

Children with SLI have do not have brain lesions, but they nevertheless have difficulties acquiring language or are much slower than the average child. They show no other cognitive deficits, they are not autistic or intellectually impaired, and they have no perceptual problems. Only their linguistic ability is affected, and often only very specific aspects of grammar are impaired.

Children with SLI have problems with the use of function words such as articles, prepositions, and auxiliary verbs. They also have difficulties with inflectional suffixes on nouns and verbs such as markers of plurality or tense. The following examples from a four-year-old boy with SLI illustrate this:

Meowmeow chase mice.
Show me knife.
It not long one.

An experimental study of several children with SLI showed that they produced the past tense marker on the verb (as in *danced*) about 27 percent of the time, compared with 95 percent by the normal control group. Similarly, the children with SLI produced the plural marker *-s* (as in *boys*) only 9 percent of the time, compared with 95 percent by the normal children.

Other studies reveal broader grammatical impairments, involving difficulties with sentences in which phrases have moved, such as *Mother is hard to please*, a rearrangement of *It is hard to please Mother*, and also with sentences involving *wh* movement. In many respects, these difficulties resemble the impairments demonstrated by agrammatic aphasics. This may suggest that certain grammatical structures or operations are particularly vulnerable to language impairment both in development and breakdown. In addition, ERP studies of certain children with SLI have shown that they do not exhibit the expected response levels for syntactic processing, which jibed with their inability to process many syntactic structures normally.

As is the case with aphasia, these studies of individuals with SLI provide important information about the nature of language and help linguists develop theories about the underlying properties of language and its development in children. Children with SLI, like the other cases of dissociation discussed above, show that language may be impaired while general intelligence remains intact, supporting the view of a grammatical faculty that is separate from other cognitive systems.

Genetic Basis of Language

Studies of genetic disorders also reveal that one cognitive domain can develop normally along with abnormal development in other domains, and they also underscore the strong biological basis of language.

Children with Turner syndrome (a chromosomal anomaly) have normal language and advanced reading skills even though they have serious nonlinguistic (visual and spatial) cognitive deficits. Similarly, studies of the language of children and adolescents with Williams syndrome reveal a unique behavioral profile in which certain linguistic functions seem to be relatively preserved in the face of visual and spatial cognitive deficits and moderate intellectual impairment. Recent studies of men with Klinefelter syndrome (another chromosomal anomaly) show quite selective syntactic and semantic deficits alongside intact intelligence.

SLI also appears to have a genetic basis. Epidemiological and familial aggregation studies show that SLI runs in families. One such study is of a large multigenerational family, half of whom are language impaired. The impaired members of this family have a very specific grammatical problem: They do not reliably use verb inflections or "irregular" verbs correctly. They routinely produce sentences such as the following:

She remembered when she hurts herself the other day.
He did it then he fall.
The boy climb up the tree and frightened the bird away.

Studies of twins show that monozygotic (identical) twins are more likely to both suffer from SLI than dizygotic (fraternal) twins, also pointing to a genetic basis to SLI.

Summary

Psycholinguistics is concerned with **linguistic performance** or processing, which is the use of linguistic knowledge (competence) in speech production and comprehension.

Comprehension, the process of understanding an utterance, requires the ability to access the mental lexicon to match the words in the utterance to their meanings. Comprehension begins with the perception of the **acoustic speech signal.** The speech signal can be described in terms of the **fundamental frequency**, perceived as pitch; the intensity, perceived as loudness; and the quality, perceived as differences in speech sounds, such as between an [i] and an [a]. The speech wave can be displayed visually as a **spectrogram**, sometimes called a **voiceprint.** In a spectrogram, vowels exhibit dark bands where frequency intensity is greatest. These are called **formants** and result from the emphasis of certain harmonics of the fundamental frequency, as determined by the shape of the vocal tract. Each vowel has a unique formant pattern.

The speech signal is a continuous stream of sounds. Listeners who know the language have the ability to segment the stream into linguistic units and to recognize acoustically distinct sounds as the same linguistic unit.

Psycholinguistic studies are aimed at uncovering the units, stages, and processes involved in linguistic performance. Several experimental techniques, including **lexical decision tasks**, have proved helpful in understanding **lexical access**. The measurement of response times, RTs, shows that it takes longer to retrieve less common words than more common words; longer to retrieve possible non-words than impossible non-words; longer to retrieve words with larger **phonological neighborhoods** than ones with smaller neighborhoods; and longer to retrieve lexically ambiguous words than unambiguous ones.

A word may **prime** another word if the words are semantically, morphologically, or phonologically related. The priming effect is shown by faster RTs to related words than to unrelated words. In addition to using behavioral data such as RT, researchers can now use various measures of electrical brain activity such as event related potentials (**ERPs**) to learn about language processing.

Perception of the speech signal and retrieval of words are necessary but not sufficient for the comprehension of speech. To get the full meaning of an utterance, the listener must **parse** the string into syntactic constituents, because meaning depends on word order and constituent structure in addition to the meaning of individual words. This is done according to the rules of the grammar of the language and also following structural parsing principles that favor simpler structures. Two such principles are **minimal attachment** and **late closure**. Other factors such as prosody, frequency of occurrence, and lexical biases can also influence the parser in its structural choices.

It is likely that we use both **top-down processing** and **bottom-up processing** during comprehension. Top-down processing uses semantic and syntactic information in addition to the lexical and phonological information drawn from the sensory input; bottom-up processing gives primacy to the information contained in the sensory input.

Language is filled with **temporary ambiguities**, points at which the sentence can continue in more than one way because of word category ambiguity or different structural possibilities. Usually these ambiguities are quickly resolved and may not be noticed except under experimental conditions.

Occasionally, the reader goes down a **garden path**, a structural misanalysis in which he must backtrack and redo the parse. **Eye tracking** techniques can determine the points of a sentence at which readers have such difficulties. These experiments provide strong evidence that the parser has preferences in how it constructs trees. Other sentences, such as multiple center embeddings, are difficult to parse because of memory constraints.

Another technique is **shadowing**, in which subjects repeat as fast as possible what is being said to them. Subjects often correct errors in the stimulus sentence, suggesting that they use linguistic knowledge rather than simply echoing sounds they hear. Shadowing experiments provide strong evidence of the use of top-down information in sentence processing.

Much of the best information about the units and stages of speech production comes from observing and analyzing spontaneous speech, especially speech errors. Many of the same factors that influence the listener in comprehension also affect the speaker in production. Lexical access is influenced in both cases by semantic and phonological relatedness of words and word frequency.

Speech errors such as **spoonerisms** show that features, segments, words, and phrases may be conceptualized or planned well before they are uttered. Anticipation errors, in which a sound is produced earlier than in the intended utterance, show that we do not produce one sound or one word or even one phrase at a time. Rather, we construct and store larger units with their syntactic structures specified.

The attempt to understand what makes the acquisition and use of language possible has led to research on the brain-mind-language relationship.

Neurolinguistics is the study of the brain mechanisms and anatomical structures that underlie linguistic competence and performance.

The brain is the most complex organ of the body, controlling motor and sensory activities, and thought processes. Research conducted for more than a century has shown that different parts of the brain control different body functions. The nerve cells that form the surface of the brain are called the **cortex**, which serves as the intellectual decision maker, receiving messages from the sensory organs and initiating all voluntary actions. The brain of all higher animals is divided into two **cerebral hemispheres**, which are connected by the **corpus callosum**, a network that permits the left and right hemispheres to communicate.

Each hemisphere exhibits **contralateral** control of functions. The left hemisphere controls the right side of the body, and the right hemisphere controls the left side. Despite the general symmetry of the human body, much evidence suggests that the brain is asymmetric, with the left and right hemispheres specialized for different functions. **Lateralization** is the term used to refer to the localization of function to one hemisphere of the brain.

Language is lateralized to the left hemisphere. Much of the early evidence for language lateralization comes from the study of **aphasia**, which is the neurological term for any language disorder that results from acquired brain damage caused by disease or trauma. Lesions in the part of the left hemisphere called **Broca's area** may suffer from **Broca's aphasia**, which results in impaired syntax and **agrammatism**. Damage to **Wernicke's area**, also in the left hemisphere, may result in **Wernicke's aphasia**, in which fluent speakers produce semantically anomalous utterances. Damage to yet different areas can produce **anomia**, a form of aphasia in which the patient has word-finding difficulties.

Deaf signers with damage to the left hemisphere show aphasia for sign language similar to the language breakdown in hearing aphasics, even though sign languages are visual-spatial languages.

Evidence for language lateralization as well as the contralateral control of function is also provided by **split-brain** patients and by neurolinguistic studies of grammatical phenomena. By studying people with aphasia and other neurological conditions such as **acquired dyslexia** localized areas of the brain can be associated with particular language functions.

Advances in technology have provided a variety of non-invasive methods for studying the living brain as it processes language. By measuring electromagnetic activities (ERPs and MEGs), and through imaging techniques such as CT, MRI, fMRI, and fPET scans, both damaged and healthy brains can be observed and evaluated. These studies confirm earlier results concerning the lateralization of language to the left hemisphere, and provide evidence of neural reflexes of various linguistic categories and constraints, such as categorical perception, phonotactic constraints, and *wh* movement. These studies also demonstrate that grammatical processing is automatic and attention-free, like a reflex.

Lateralization of language to the left hemisphere is a process that begins very early in life. Numerous neurolinguistic studies have found that brain organization for language and grammar found in adults is already reflected in the brains of newborns and young infants. Infants also show evidence of the many of the neural correlates of linguistic categories that we observe in adults.

While the left hemisphere is innately predisposed to specialize for language, there is also evidence of considerable **plasticity** in the system during the early stages of language development. Children who undergo a left **hemispherectomy** experience an initial period of aphasia, but in certain cases may reacquire a linguistic system like that of normal children. The plasticity of the brain decreases with age and with the increasing specialization of the different hemispheres and regions of the brain.

The **critical-age hypothesis** states that there is a window of opportunity for learning a first language. The imperfect learning of grammatical rules in people exposed to language after this period supports the hypothesis.

The language faculty is **modular**. It is independent of other cognitive systems with which it interacts. Evidence for modularity is found in the selective impairment of language in aphasia, in children with **specific language impairment (SLI)**, in linguistic **savants**, and in children who learn language past the critical period. The genetic basis for an independent language module is supported by studies of SLI in families and twins and by studies of genetic anomalies associated with language disorders.

References for Further Reading

Ahlsén, E. 2006. *Introduction to neurolinguistics*. Amsterdam: John Benjamins.

Caplan, D. 2001. *Neurolinguistics: The handbook of linguistics*, M. Aronoff and J. Rees-Miller (eds.). London: Blackwell Publishers.

Carroll, D. W. 2007. *Psychology of language, 5th ed.* Belmont, CA: Wadsworth.

Curtiss, S. 1977. *Genie: A linguistic study of a modern-day "wild child."* New York: Academic Press.

Curtiss, S. 2013. Revisiting modularity: Using language as a window to the mind. In M. Piatelli-Palmarini and R.C. Berwick (Eds.) *Rich Languages from Poor Inputs*. Oxford: Oxford University Press, 68–90.

Damásio, H. 1981. Cerebral localization of the aphasias. *Acquired aphasia*, M. Taylor Sarno (ed.). New York: Academic Press, 27–65.

Fernandez, E.M. and Cairns, H.S. 2010. *Fundamentals of psycholinguistics*. Oxford, UK: Wiley-Blackwell.

Fromkin, V. A. (ed.). 1980. *Errors in linguistic performance*. New York: Academic Press.

Gazzaniga, M. S. 1970. *The bisected brain*. New York: Appleton-Century-Crofts.

Geschwind, N. 1979. Specializations of the human brain. *Scientific American* 206 (September): 180–199.

Ingram, J. 2007. *Neurolinguistics: An introduction to spoken language processing and its disorders*. Cambridge, U.K.: Cambridge University Press.

Johnson, K. 2003. *Acoustic and Auditory Phonetics, 2nd ed.* Oxford, UK: Blackwell.

Ladefoged, P. 1996. *Elements of acoustic phonetics*, 2nd ed. Chicago: University of Chicago Press.

Lenneberg, E. H. 1967. *Biological foundations of language*. New York: Wiley.

Obler, L. K., and K. Gjerlow. 1999. *Language and brain*. Cambridge, UK: Cambridge University Press.

Patterson, K. E., J. C. Marshall, and M. Coltheart (eds.). 1986. *Surface dyslexia*. Hillsdale, NJ: Lawrence Erlbaum.

Pinker, S. 1994. *The language instinct*. New York: William Morrow.

Poizner, H., E. S. Klima, and U. Bellugi. 1987. *What the hands reveal about the brain*. Cambridge, MA: MIT Press.