Chapter 2

Basic Brain Anatomy

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To understand how a part of the brain is disordered by damage or disease, speech-language pathologists must first know a few facts about the anatomy of the brain in general and how a normal and healthy brain functions. Readers can use the anatomy presented here as a reference, review, and jumping off point to understanding the consequences of damage to the structures discussed. This chapter begins with the big picture and works down into the specifics of brain anatomy.

The Central Nervous System

The nervous system is divided into two major sections: the central nervous system and the peripheral nervous system. The **central nervous system** (CNS) consists of the brain and spinal cord. The **peripheral nervous system** (PNS) consists of the nerve tracts that connect the rest of the body to the central nervous system. An easy way to differentiate the CNS and the PNS is to remember that the CNS is entirely encased in bone whereas the PNS is not (**Figure 2-1**).

The Brain

The average weight of an adult human brain is about 3 pounds. That is about the weight of a single small cantaloupe or six grapefruits. If a human brain was placed on a tray, it would look like a pretty unimpressive mass of gray lumpy tissue (Luria, 1973). In fact, for most of history the brain was thought to be an utterly useless piece of flesh housed in the skull. The Egyptians believed that the heart was the seat of human intelligence, and as such, the brain was promptly removed during mummification. In his essay *On Sleep and Sleeplessness*, Aristotle argued that the brain is a complex cooling mechanism for our bodies that works primarily to help cool and condense water vapors rising in our bodies (Aristotle, republished 2011). He also established a strong argument in this same essay for why infants should not drink wine. The basis for this argument was that infants already have too much moisture in their heads. Nonetheless, thanks to advancements in the fields of science, medicine, and the birth of the fields of psychology and neurology, we

Central nervous system The brain and spinal cord.

Peripheral nervous system The nerve tracts outside of the central nervous system that work to connect the central nervous system to the rest of the body.

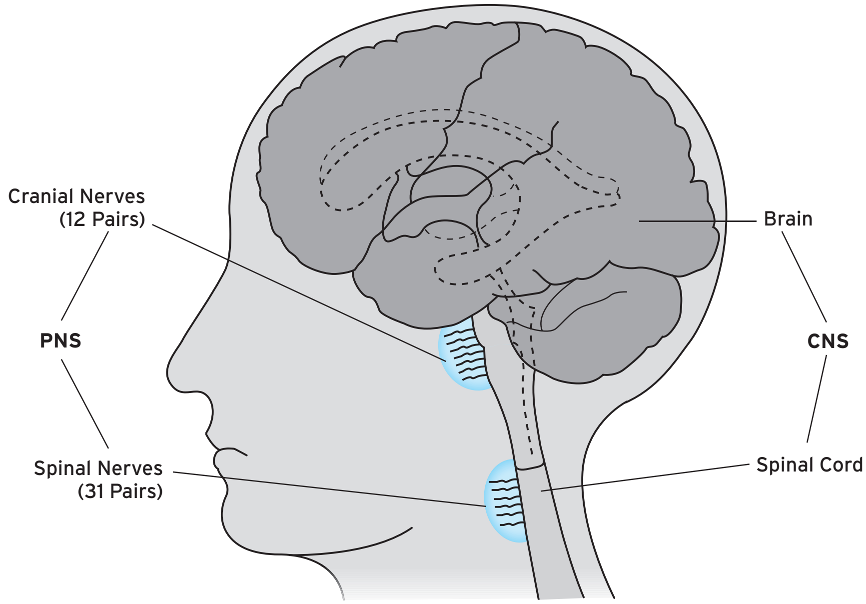

Figure 2-1 The central and peripheral nervous systems.

now know that the brain is much more than an inert mass of head stuffing. And though we know Aristotle was correct in stating that infants should not drink wine, we know that it is not because infants are born with copious amounts of head vapors. We know now that the brain is the organ that coordinates and regulates all functions and other organs in our bodies. It is the seat of consciousness, intelligence, and language.

The brain has three gross divisions, the cerebrum, the brain stem, and the cerebellum (**Figure 2-2**).

When asked to describe a brain, most individuals describe the cerebrum of the brain. This is the most recently evolved and most easily recognizable part of the brain. The **cerebrum** is the rounded gray section of the brain riddled with tiny ridges and valleys that makes so many appearances in zombie movies. The cerebrum rests on top of the brain stem. The cerebrum houses our highest and most complex cognitive functions. This is where our consciousness originates as well as our ability to do things such as produce language and cognition and organize body movements. The surface tissue of the cerebrum is known as the **cerebral cortex**. The cortex is the most superficial layer of the cerebrum (**Figure 2-3**).

Cerebrum The rounded gray section of the brain with gyri and sulci.

Cerebral cortex The most superficial layer of the cerebrum.

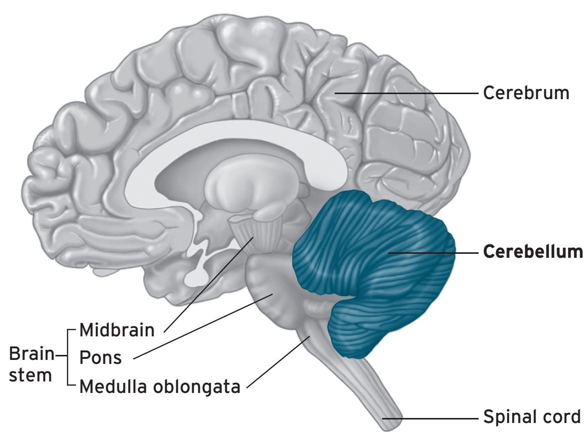

Figure 2-2 Cerebrum, brain stem, and cerebellum.

The cerebral cortex is gray and folded and marked by various ridges and valleys. The cerebrum is folded in on itself so that more neural tissue can be packed

Figure 2-3 Cerebral cortex.

into a much smaller space. The gray coloration of the surface of the cerebral cortex results from the gray color of the cell bodies of the neurons and is therefore said to consist of gray matter. **Gray matter** is where processing and regulating of information occurs in the CNS. Gray matter is found in the cortex and some subcortical structures such as the cerebellum, thalamus, basal ganglia (to be discussed), in addition to the spinal cord. This is in contrast to **white matter**. The white matter of the CNS consists of the axons of neurons that are covered in a white sheath of a protein and fatty substance called **myelin**. Myelin insulates the axons of neurons (like a rubber sheath insulates the copper wire in electrical wiring) and allows electrical chemical impulses of the nervous system to be conducted at approximately 100 meters per second. Unmyelinated neurons are able to conduct neural impulses only at about 1 meter per second. White matter is responsible for connecting different areas and structures of the brain to one another and enabling them to communicate.

Gray matter Unmyelinated neurons responsible for the processing and regulating of information within the nervous system.

White matter Myelinated neurons responsible for the transmission of impulses from one area of the brain to another.

Myelin An insulating layer of protein and fatty substances that forms a layer around the axons of certain neurons, which allows for the fast and effective transmission of neural impulses.

The myelinated axons of neurons make white matter appear white and the lack of myelin makes gray matter gray. There are three primary types of white matter tracts in the CNS: association fibers, commissural fibers, and projection fibers. **Association fibers** are the pathways of white matter that connect different structures and areas of the brain in a single hemisphere. **Commissural fibers** are white matter pathways that connect analogous areas between the two cerebral hemispheres. **Projection fibers** are white matter tracts that project from the brain to the spinal cord and transmit motor (movement) signals from the CNS out to the PNS and sensory signals from the PNS back up through the lower CNS to be processed in the brain.

Certain diseases attack and break down the myelin sheath of white matter. These are known as demyelinating illnesses. Demyelinating illnesses degrade the potential of neurons to conduct neural impulses. This degradation of the myelin inhibits appropriate neural functioning by disrupting communication between different areas of the CNS or PNS, or both. Amyotrophic lateral sclerosis (ALS) and multiple sclerosis are two such demyelinating diseases. See the video, *Living with Multiple Sclerosis* for a discussion of this disease as well as an interview with an individual living with multiple sclerosis.

The folds on the cerebral cortex are created by small convolutions and furrows, or ridges

Association fibers White matter pathways that connect different structures and areas of the brain within a single hemisphere.

Commissural fibers White matter pathways that connect analogous areas between the two cerebral hemispheres.

Projection fibers White matter pathways that project from the brain to the spinal cord and transmit motor (movement) signals from the CNS out to the PNS and also transmit sensory signals from the PNS back up through the lower CNS to be processed in the brain.

and valleys. The ridges are known as **gyri** (singular: gyrus). The valleys are known as **sulci** (singular: sulcus). (See the following Clinical Note on lissencephaly for a discussion of the clinical relevance of the gyri and sulci.) Deeper grooves that make more pronounced divisions in the anatomy of the brain are referred to as **fissures**. Knowledge of the major gyri, sulci, and fissures is important to learning about the rest of the anatomy of the brain because they are important landmarks for describing the location of many other areas and structures of the brain. The following sections on the cerebral hemispheres and the major cerebral lobes revisit the importance of these structures.

Between the surface of the brain and the skull are three anatomic layers of tissue known as the **cerebral meninges**. The outermost of these layers is the dura mater. The **dura mater** (Latin for *tough mother*) is a dense, fibrous protective layer of tissue enveloping the brain and spinal cord. Beneath the dura mater is the arachnoid mater. The **arachnoid mater** is a far more delicate layer of tissue than the dura mater. The arachnoid mater wraps the brain and spinal cord and plays a large role in supplying blood to the surface of the brain by the

Gyri Ridges forming the visible portion of the cerebral cortex.

Sulci Inward folds of the cerebral cortex.

Fissure A deep groove that creates major divisions in the anatomy of the brain.

Lissencephaly A group of congenital malformations that create a lack of appropriate gyri and sulci of the cortex and a consequent reduction in cortical tissue.

Cerebral meninges Three layers of tissues with various functions that encase and envelope the brain and spinal cord.

Dura mater A dense, fibrous protective layer of tissue that envelopes the brain and spinal cord. This is the superficial-most layer of the cerebral meninges.

Arachnoid mater A layer of the cerebral meninges that exists between the dura mater and the pia mater that plays a large role in supplying blood to the surface of the brain through the many blood vessels it contains.

Clinical Note

Lissencephaly

As mentioned, the human cerebrum is folded in on itself to allow far more cortical tissue to be packed into the skull. If you smoothed out the gyri and sulci of the human cortex, the surface area would be far greater than that of the inside of the skull. This system of folding allows the body to fit as much cortical tissue within the skull as possible. It is this great amount of cortex that allows for normal cognitive functioning. However, there is a group of congenital malformations categorically referred to as **lissencephaly**, or smooth brain syndrome, in which the brain develops in the mother's womb without these folds in the cortex (**Figure 2-4**). There are many different etiologies that account for the varying types of lissencephaly. Some etiologies are viral infection and gene mutation. Children who are born this way usually have profound neurologic impairments, feeding difficulties, and can have a very short life span. Nonetheless, lissencephaly does occur on a spectrum and the long-term medical and developmental prognosis of an affected child depends on the level of severity of the brain disorder.

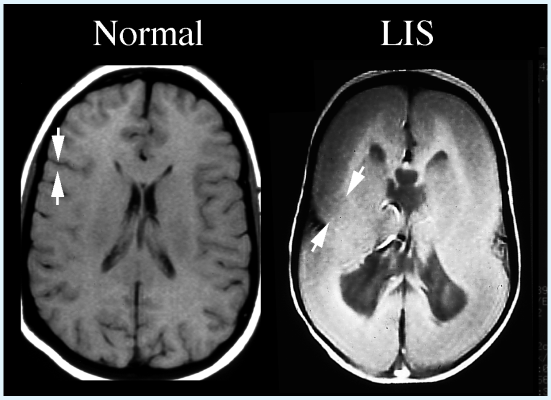

Figure 2-4 Imaging scan of a normally developed brain and cortex alongside a lissencephalic brain. Missing from the lissencephalic brain are the many folds of cortical tissue seen in the normally developing brain.

Source: Courtesy of Dr. Joseph G. Gleeson, University of California San Diego many blood vessels that it contains. The arachnoid mater is so named because of the dense spider-web-like appearance of the blood vessels in this layer. The **pia mater** (Latin for *gentle mother*) is the innermost and most delicate meningeal layer. The pia mater closely hugs the surface of the brain and spinal cord as it rises and falls along the gyri, sulci, and fissures of the brain. Blood vessels from the arachnoid mater pass through the pia mater to nourish the surface of the brain and spinal cord. **Figure 2-5** shows the dura mater as it is being pulled back from the brain below to expose the **leptomeninges** (i.e., the arachnoid mater and the pia mater). See Figure 2-14 for an image depicting the meningeal layers.

Figure 2-5 Head autopsy revealing dura mater and leptomeninges.

Courtesy of Department of Health and Human Services, Centers for Disease Control and Prevention. Dr. Edwin P. Ewing, Jr.

The Cerebral Hemispheres

Observable on the surface of the brain is a deep groove running front to back. This groove is known as the **longitudinal fissure** and it runs the length of the brain and divides the brain into left and right halves. These halves are known as the left and right cerebral hemispheres (**Figure 2-6**).

Generally speaking, each cerebral hemisphere is responsible for different cognitive and motor functions. For instance, the right hemisphere is responsible for movement of the left side of the body and processing sensory information coming up to the brain from the left side of the body. The left hemisphere is responsible for moving the right side of the body and processing sensory information coming up to the brain from the right side of the body.

Although the hemispheres are often spoken of as discrete and separate units that operate independently, it is a false and outdated assumption that each hemisphere performs its own functions in isolation without input from the other. The two hemispheres work in tandem and communicate with one another by a mass of white matter tracts known as the **corpus callosum**. The corpus callosum is located between the cerebral hemispheres and is found deep within the longitudinal fissure, at its very base. The corpus callosum houses the largest white matter pathways responsible for connecting the left and right hemispheres. See the following Clinical Notes on split-brain syndrome.

Pia mater The innermost and most delicate layer of the cerebral meninges that hugs the surface of the brain and spinal cord closely as it rises and falls along the gyri, sulci, and fissures of the brain.

Leptomeninges The thin layers of the meninges including the arachnoid mater and the pia mater.

Longitudinal fissure A deep groove running front to back along the brain that divides the brain into the right and left cerebral hemispheres.

Corpus callosum A mass of white matter tracts located at the base of the longitudinal fissure that connects the analogous areas between the two hemispheres.

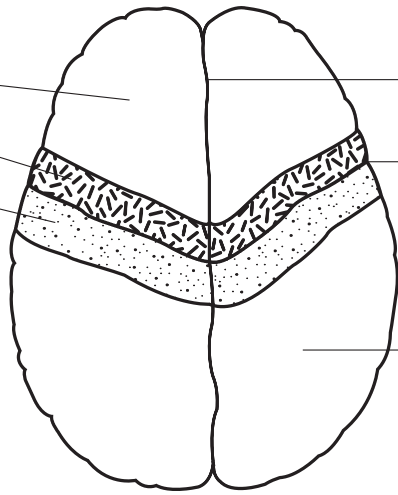

Figure 2-6 A superior view of the cerebral hemispheres.

See the *Split Brain Demonstration* video for a live demonstration.

Typically, the left cerebral hemisphere is the hemisphere that houses most language abilities. Also, most individuals are right handed. This creates the situation where the language-dominant hemisphere (most often the left hemisphere) also controls a person's writing hand (most often the right hand). More often than not, the right cerebral hemisphere is not the language-dominant hemisphere. Even in left-handed individuals the left hemisphere usually

Clinical Note

Split-Brain Syndrome

All brains operate using electricity. Electrical chemical impulses are how our brains communicate with themselves and our bodies. However, it is possible to have too much electricity generated in the brain. A seizure is a result of an excess and pathologic amount of electricity in the brain. Seizures can be very dangerous and can create severe and permanent damage to the brain and even death. The most common group of seizure disorders are categorized as forms of epilepsy. In some very severe forms of epilepsy, seizure activity is so threatening to an individual's brain that it is deemed necessary to perform a surgery on the two cerebral hemispheres by cutting the corpus callosum. This surgery, known as a corpus commisurotomy, decreases seizures but results in what is known as split-brain syndrome. Individuals with split-brain syndrome have cerebral hemispheres that are unable to communicate with one another. This makes perception sometimes difficult and creates motor problems as well. With the modernization and perfection of this surgery in the 1960s and 1970s, scientists were able to study the functioning and abilities of the individual cerebral hemispheres in isolation from one another.

Clinical Note

Split-Brain Demonstration

Find a friend and try this little experiment to demonstrate to yourself the value of communication between your right and left cerebral hemispheres. You need a friend and a shoe with laces.

To begin, take the shoe in your own hands, close your eyes, and tie the laces with your eyes closed. Probably this isn't a difficult task for you. Your brain can draw on years of motor memory developed by the thousands of times you have tied your shoes. As you are tying the shoe, your left cerebral hemisphere is controlling your right hand and your right cerebral hemisphere is controlling your left hand. Your hands probably move dexterously together as if they know exactly what the other is doing, even though you have your eyes closed. In fact, each hand does know what the other is doing because your left and right cerebral hemispheres are communicating with each other by the corpus callosum and telling each other what the other is doing with each hand.

Now, sit side by side with your friend. The two of you should be shoulder to shoulder. One of you lace your arm under the arm of the other (**Figure 2-7**) so that each of you has one hand that will attempt to work together with the other to tie the shoe. Now there is a left and a right hand each controlled by a separate cerebral hemisphere. This is almost just like when you tied your shoe yourself but with an important difference. The difference is that when you were by yourself, the two cerebral hemispheres controlling the hands were connected. With your friend, the two cerebral hemispheres controlling the hands are not connected at all and, therefore, cannot communicate with one another (you are not allowed to talk to your friend or open your eyes as you do this experiment). Therefore, one hemisphere does not know what the other hemisphere's hand is doing.

In this side-by-side position where each of you contribute the use of one hand, hold the untied shoe, both of you close your eyes, and attempt to tie the shoe. Probably you'll find it far more difficult than when you attempted this task by yourself. Why is this? It is because each hand does not know exactly what the other is going to do and when. Individuals with split-brain syndrome face these motoric problems on all tasks requiring more than one side of the body.

Figure 2-7 Split-brain demonstration.

houses language or a greater part of it. Although certainly not always the case, in the rest of this book, unless otherwise stated, it is assumed for the sake of brevity that the term *left hemisphere* is synonymous with *language-dominant hemisphere* and *right hemisphere* is synonymous with *nondominant hemisphere for language*.

Right Cerebral Hemisphere

If the brain was neglected as an important organ for most of known history, then the right hemisphere has suffered almost the same fate since the inception of serious study of the brain. For most of the history of neuroscience, the right hemisphere was deemed most insignificant and such terms as *silent*, *minor*, *unconscious*, or *subordinate* were almost universally applied when describing the right hemisphere. Only in the last 20 to 30 years (really beginning with the split-brain studies of the 1960s and 1970s) has the scientific community come to acknowledge the right hemisphere as a truly significant structure in cognition and language. In fact, damage to the right hemisphere produces some of the most bizarre and noteworthy deficits in neurology.

As it is understood now, the right hemisphere plays some very important roles in communication. Communication not only involves language but facial expressions, body language, gestures, and prosody of speech. It is these nonlinguistic aspects of communication that the right hemisphere specializes in. The right hemisphere deals heavily in the perception of emotion by processing these nonlinguistic components of communication. The appropriate processing of nonlinguistic aspects of communication can facilitate effective communication and mutual understanding between speakers, whereas a failure to process nonlinguistic information appropriately can completely derail efforts at communication.

In regard to speech, the right hemisphere is responsible for our perception of prosody. **Prosody** is the changes in tone and intensity we use when we speak that allow us to give the words we say an emotional component. Usually most of the emotional content of speech (the mood and emotional state of the person) is conveyed in prosody. For instance, when a person is angry, a listener often does not really need to hear the actual words said to know that the speaker is angry. The listener will probably be able to detect anger in the speaker's prosody, their tone of voice. Or when a person produces a verbal insult, a listener can tell the utterance is meant to be an insult even if they don't understand the language or have never heard the insult. Another example is of two people arguing in a closed room. Listeners in adjacent rooms might hear the muffled sound of these two people arguing. Even though the listeners might not hear the actual words spoken, they cannot mistake the angry tone of the voices as two people having a pleasant conversation. The right hemisphere allows people to perceive emotions through interpretation of prosody.

Prosody The changes in pitch, stress, timbre, cadence, and tempo a person uses to infuse utterances with emotional content.

The ability to comprehend the information embedded within prosody and other nonlinguistic signals during communication is especially important in social interactions because, often, the words that a person says do not reflect the true intent of the utterance. For example, when a person says, "It is a beautiful day" accompanied by a pleasant smile, she probably is communicating that it is, in fact, a beautiful day. However, by using a sarcastic tone, furrowing her brows, and snarling her upper lip, she can use the words "It is a beautiful day" to communicate very effectively that she does not believe that the day is beautiful in any way, shape, or form. The right hemisphere enables listeners to know that the literal interpretation of a person's words does not always accurately reflect the thoughts the speaker intends (or does not intend) to communicate. Due to the loss of these abilities, individuals with right hemisphere damage tend to be very concrete in their comprehension of language. For example, if asked to explain the phrase "She is warm-hearted," an individual with right hemisphere damage might state that the person in question has a heart temperature that is much higher than most other people's hearts.

Processing and recognizing faces and facial expressions are also right hemisphere responsibilities. A loss of the ability to perceive and recognize faces often follows damage to the right occipital area (Luria, 1973). Difficulty with the visual processing of the faces of others is known as **prosopagnosia**. In severe cases, individuals with lesions in the occipital area of the right hemisphere might have difficulty recognizing the faces of their loved ones or even their own face. In less severe cases, they might simply be unable to interpret facial expressions appropriately. Their understanding of the communicative intent of others can be affected by this.

The right hemisphere is responsible not only for comprehending emotion in speech and on faces, but also for producing appropriate prosody and facial expression to convey emotion. Individuals who have damage to the right cerebral hemisphere can often appear expressionless and sound monotone and emotionless to listeners. Hence, listeners might not be able to perceive that a person with right hemisphere damage is in a highly agitated state or experiencing some other strong emotion as it is occurring because of these deficits. Clinically, this can make the treatment of cognitive deficits in individuals with right hemisphere damage difficult as the speech-language pathologist may have no idea of the frustration or enthusiasm level of the patient.

The right hemisphere is also responsible for processing melody and rhythm in music. Individuals who have experienced right hemisphere damage can display **amusia**, or the loss of the ability to recognize and interpret music (Luria, 1973). Amusia can also affect the ability of the person to produce music as well as hear and interpret it correctly.

The right hemisphere also is largely responsible for the perception of environmental sounds. Damage to certain areas in the right hemisphere might result in a lack of ability to discern the meaning of nonspeech sounds that occur in the environment such as a door slamming, a car driving by, or a bird singing (Joseph, 1988). This can happen in the absence of any difficulty interpreting speech sounds. See the following discussion on the temporal lobe for more specific information regarding this function of the right hemisphere.

Also significant is that the right hemisphere has a role in processing the **macrostructure**, or gestalt. **Macrostructure processing** is the ability to effectively piece together many smaller details (microstructure) to arrive at the correct perception of the big picture (the macrostructure). An example of macrostructure processing is being able to perceive four wheels, doors, trunk, hood, and headlights and from that being able to perceive that the object is a car. Individuals with deficits of macrostructure processing tend to perseverate on details and cannot piece together the details and perceive the whole. Therefore, individuals with right hemisphere lesions are often known as being unable *to see the forest for the trees*.

Prosopagnosia A neurologic deficit in the specific ability to cognitively process sensory information regarding the faces of others for the purposes of recognition.

Amusia An acquired deficit in the ability to interpret and recognize music.

Macrostructure The bigger picture composed of many details. Also known as the gestalt.

Macrostructure processing The ability to generate a correct perception of macrostructure.

Visuospatial processing The ability to understand visual information, visual representations, and spatial relationships among objects.

The spatial component of math skills as well as **visuospatial processing** is also a primary responsibility of the right hemisphere. Examples of some specific visuospatial skills are perception of depth, distance, and shape; localizing targets in space; and identifying

Broca's area The inferior, posterior region of the frontal lobe of the left hemisphere that is a specialized area of the cerebrum responsible for finding and assembling words for the appropriate expression of thought.

Wernicke's area A specialized portion of the cerebrum located at the superior marginal gyrus of the left hemisphere's temporal lobe that is responsible for interpreting and deriving meaning from the speech of others.

Central sulcus A deep groove that runs down the middle lateral surface of each cerebral hemisphere.

Lateral sulcus A deep groove that begins at the lower frontal aspect of each of the two cerebral hemispheres and travels at an upward angle, passes the central sulcus, and then terminates.

figure–ground relationships (Joseph, 1988). Visuospatial processing skills are used to piece together a jigsaw puzzle, sink a basket in a basketball game, and successfully navigate your body from place to place past and around innumerable obstacles.

The right hemisphere also plays a great role in the ability to attend to stimuli. There are various levels of attention, and the right hemisphere plays a role in regulating most kinds. Specifically, the right hemisphere specializes in the ability to keep attention on a single stimulus for an extended period of time (sustained attention) and the ability to ignore unimportant stimuli while sustaining attention on important stimuli (selective attention). An example of sustained attention is paying attention to a lecture in a classroom. If a lawn mower is running outside the classroom during the lecture, then students must actively block out the distracting sound of the lawn mower to focus on the lecture, which is an example of selective attention.

Left Cerebral Hemisphere

As mentioned, the left cerebral hemisphere has been the subject of study more than the right hemisphere has. This is mostly because the left hemisphere typically is the hemisphere that houses language. The discovery that certain locations in the left hemisphere are responsible for expressive and receptive language skills cued researchers in the late 1800s to begin examining the relationship between brain and cognition more closely.

In 1861, Paul Broca published the results of his studies indicating that the inferior, posterior region of the frontal lobe of the left hemisphere is responsible for finding and assembling words for the appropriate expression of thought. This area is now known as **Broca's area** (**Figure 2-8**). Damage to this area can produce what is known as Broca's aphasia. Individuals with this disorder usually know what they want to say but cannot find the right words.

A few years later in 1874, Carl Wernicke localized receptive language to the superior marginal gyrus of the left hemisphere's temporal lobe. This area is now known as **Wernicke's area** (Figure 2-8). Wernicke's area is responsible for interpreting and deriving meaning from the speech of others. Damage to this area produces a condition known as Wernicke's aphasia. Individuals with this disorder cannot comprehend the speech of others, and their own speech is often nonsensical and nonstop.

The Major Cerebral Lobes

Two important sulci are the **central sulcus** and the **lateral sulcus** (Figure 2-8). The central sulcus, also known as the fissure of Rolando or the central fissure, runs down the middle lateral surface of each cerebral hemisphere. The lateral sulcus, also known as the sylvian fissure, begins at the lower frontal aspect of each of the two cerebral hemispheres, travels at an upward angle, passes the central sulcus, and then terminates. The central and lateral sulci create important divisions among the major sections, or lobes, of the cerebrum. The lobes of the cerebrum are each named for the bones of the cranium that overlay them.

As the central sulci run down the side of each cerebral hemisphere they create a division between the

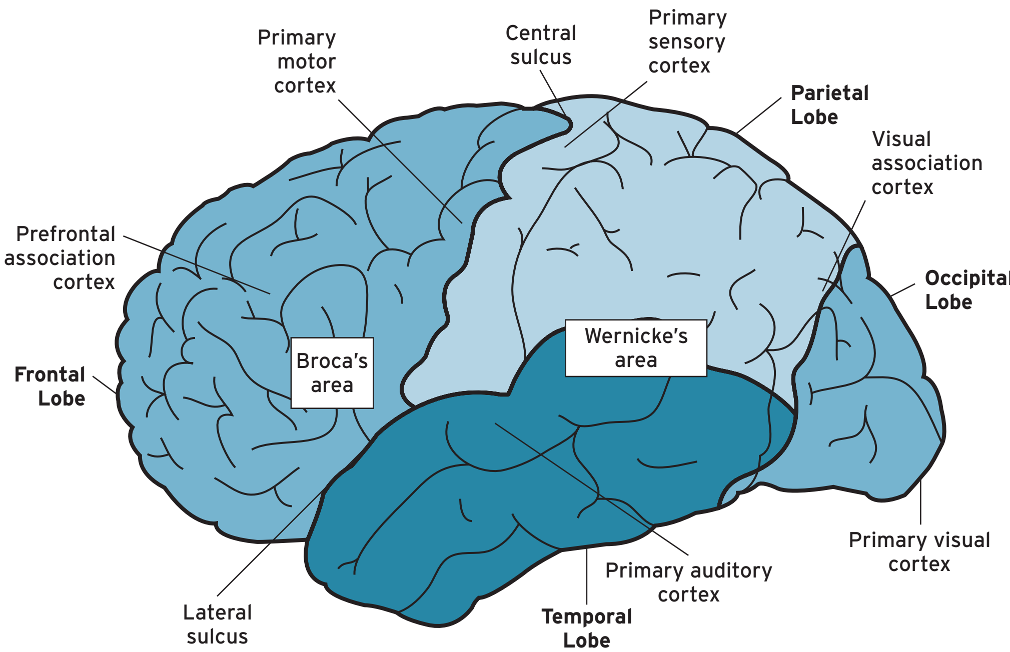

Figure 2-8 External surface of the left cerebral hemisphere.

frontal lobes and the parietal lobes (Figure 2-8). The lateral sulci create a division between the temporal lobes and the above frontal and parietal lobes (Figure 2-8). These are both unlike the longitudinal fissure, which divides the brain into right and left cerebral hemispheres.

Each cerebral lobe houses different major functions of the brain and specializes in certain functions.

The left **frontal lobe** (Figure 2-8) houses expressive language in Broca's area in the inferior and posterior sections. The frontal lobes also play a large role in motor movement. All voluntary movement originates in the anterior portion of the brain (i.e., the frontal lobes). The frontal lobes house cortical areas responsible for the initiation and construction of plans for motor movement such as the **primary motor cortex**, which is also known as the motor strip (Figure 2-8). The primary motor cortex is located on the most posterior gyrus of the frontal lobe, just in front of the central sulcus. The primary motor cortex is responsible for issuing motor plans for volitional movement. More surface area of the cortex within the primary motor cortex is devoted to body parts that are capable of producing delicate or fine motor movements, including the face, lips, mouth, and hands. Less cortical tissue in the primary motor cortex is dedicated to the control of body parts that execute only gross motor functions. The knee, for instance, has less surface area dedicated to its control within the primary motor cortex than does the mouth or hands. The spatial representation of

Frontal lobes The most anterior sections of the cerebral hemispheres that are delineated posteriorly by the central sulcus and inferiorly by the lateral sulcus and that houses expressive language and deals heavily in motor movement.

Primary motor cortex A strip of tissue oriented vertically along the last gyrus of each frontal lobe that plays a large role in voluntary motor movement.

Motor homunculus A visual illustration of the amount of cortical tissue dedicated to the movement of each body part within the primary motor cortex.

Parietal lobes A section of the cerebrum located posterior to the frontal lobes and anterior to the occipital lobes that is largely responsible for receiving and processing sensory information concerning the body.

Primary sensory cortex A section of cortex along the first gyrus of the parietal lobes dedicated to receiving and processing sensory information.

Proprioception An individual's sense of where their extremeties and their body is in space.

Sensory homunculus A visual illustration of the amount of cortical tissue within the primary sensory cortex dedicated to processing sensory information from each body part.

Frontal lobotomy A procedure of damaging or removing tissue from the prefrontal area of the frontal lobes for the supposed remediation of psychological problems.

Temporal lobe A section of the cerebrum located inferior to the parietal lobes that is largely responsible for memory and processing of auditory stimuli.

the amount of space in the brain dedicated to the movement of each body part is represented by an illustration known as the **motor homunculus**. The word homunculus is Latin for *little man* (**Figure 2-9**).

The left primary motor cortex is responsible for issuing motor movements for speech. Damage at or near Broca's area, near the base of the left primary motor cortex, disrupts the brain's ability to execute appropriate motor plans for speech. This condition is known as apraxia of speech.

The frontal lobes, specifically the prefrontal regions (the very front of the frontal lobes), also store personality and some memory. Damage to the prefrontal regions of the frontal lobes can produce changes in personality ranging from mild to drastic. Examples of these changes include a sudden lack of social inhibitions leading to inappropriate sexual advances or physical/verbal aggression, or impulsivity. However, less obvious changes in personality can also take place, such as changes in food and clothing preferences. See the following Clinical Notes on Phineas Gage and frontal lobotomies.

The **parietal lobes** are located behind the frontal lobes (Figure 2-8) and are responsible for receiving and processing sensory information concerning the body. The first gyrus of the parietal lobes house the **primary sensory cortex** (Figure 2-8), also known as the sensory strip. This section of cortex receives and processes tactile information coming from the body as well as proprioceptive information. The left primary sensory cortex receives sensory information from the right side of the body, and the right primary sensory cortex receives sensory information from the left side of the body. **Proprioception** is an individual's sense of where their extremities and their body is in space. For instance, when an individual closes his eyes and extends his arms in front of himself, he can feel his arms out there and knows exactly where they are in space, despite having his eyes closed.

More cortical tissue within the primary sensory cortex is dedicated to body parts that have higher numbers of sensory receptors than those that have fewer. For instance, the mouth and lips are very sensitive to touch and to temperature. Accordingly, very large sections of the primary sensory cortex are dedicated to receiving and processing sensory information coming from the mouth and lips. In contrast, the skin on the back has far fewer sensory receptors and therefore has very little representation in the primary sensory cortex. As in the primary motor cortex, the topographical arrangement of cortical tissue representing the associated body parts creates an arrangement that is referred to as the sensory homunculus. On the **sensory homunculus**, body parts that have the most cortical tissue dedicated to processing their sensory information are represented as being larger than those body parts that have little cortical tissue dedicated to processing their tactile and proprioceptive information (Figure 2-9). Extending the previous example, the mouth and lips on the sensory homunculus are quite large, while the trunk of the sensory homunculus is very small.

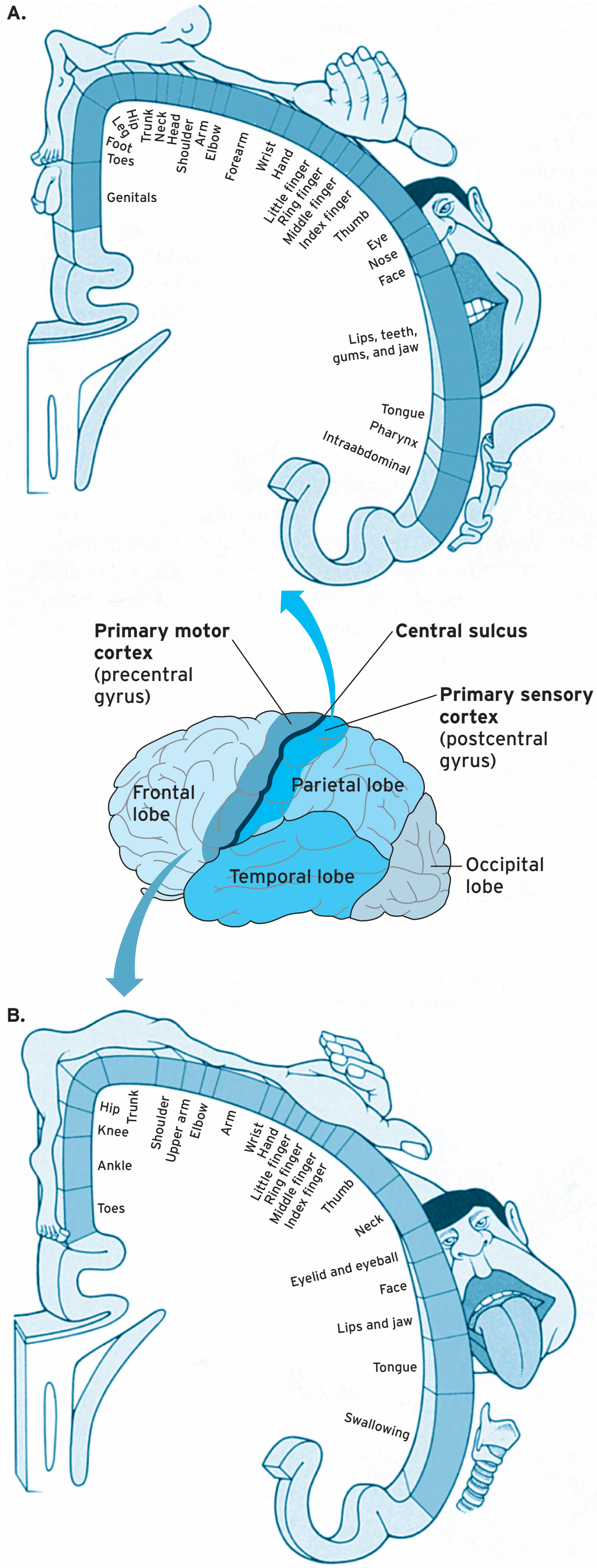

Figure 2-9 A. Sensory homunculus. B. Motor homunculus.

Clinical Note

Frontal Lobotomy

In the 1940s and 1950s, the **frontal lobotomy**, a procedure of damaging or removing tissue from the prefrontal area of the frontal lobes for the supposed remediation of psychological problems, was at its height. This procedure was popularized in the United States by Dr. Walter Freeman, whose name is closely associated with the procedure though use of the frontal lobotomy was widespread (Acharya, 2004).

The frontal lobotomy began as a surgical procedure to treat those with profound schizophrenia. At this point, the frontal lobotomy was still considered a highly experimental procedure (Kucharski, 1984). Freeman and most other medical professionals of the time initially used the frontal lobotomy as only a last-resort treatment. However, Freeman eventually came to believe that once psychological problems got to a certain level of severity, patients became unresponsive to other treatments. Following this belief, he shifted his position to using the frontal lobotomy as a more general treatment to be applied earlier to a range of problems including depression, criminality, schizophrenia, alcoholism, obsessive-compulsive disorder, and hysteria among others (Acharya, 2004; Kucharski, 1984).

To perform this treatment as often and as efficiently as necessary to meet his new criteria, Freeman abandoned the surgical suite, the surgical team, and general anesthesia. In his office, he began knocking his patients out with electroshock (electric currents to the brain) and inserting ice picks through the orbital process of their skull behind their eyes and moving the ice picks back and forth in a lateral (side-to-side) fashion, effectively damaging the prefrontal areas of the frontal lobes. Thousands and thousands of individuals were lobotomized in this manner during the 1940s and 1950s in assembly-line-like procedures. Eventually, Freeman abandoned the use of ice picks, which occasionally broke off in the skulls of his patients, and had custom instruments made that were far stronger than the average ice pick.

Despite grossly inconsistent results from the procedure, varying from improvement of conditions to extreme worsening of conditions and severe side effects, Freeman continued advocating for the procedure well after pharmaceutical treatments in the mid-1950s had been developed to target the same psychological conditions (Acharya, 2004). The frontal lobotomy was a product of its time and part of the scientific zeitgeist of the 1940s and 1950s. In retrospect, it is seen as being accepted too enthusiastically and blindly as an effective procedure by not only the scientific community but the popular culture at large willing to subject their loved ones to the procedure.

Clinical Note

Phineas Gage

Perhaps the most famous case documenting personality change following damage to the frontal lobes is that of Phineas Gage. Mr. Gage was a railway construction worker who lived in the mid-1800s. He was known to those around him to be moderate in his habits and possessing self-restraint and was rarely known to be profane (MacMillan, 2000). In 1848, while Mr. Gage was packing explosive powder into a hole to clear away rock for a railway, the explosives ignited unexpectedly and blew the metal tamping rod he was using beneath his cheekbone up through the frontal lobes of his brain and out through the top of his skull (**Figure 2-10**). This injury damaged both his frontal lobes and took out his left eye. It is generally accepted that he might not have lost consciousness from the injury. He is said to have sat upright in the cart that drove him to see a doctor (MacMillan, 2000).

Despite the severity of the injury, Mr. Gage lived and had generally recovered after 3 months (MacMillan, 2000). However, it was noted by friends and relatives that his personality changed dramatically after his accident. He was reported to have become very uninhibited and had difficulties not indulging in all his desires. He also had significant memory loss. His employers found that he could no longer complete his previous duties in railway construction. Years after his death his skull was exhumed and it was determined that the areas of Mr. Gage's brain that were damaged by the metal rod were within the frontal cortex, parts of the brain responsible for inhibiting socially inappropriate behavior.

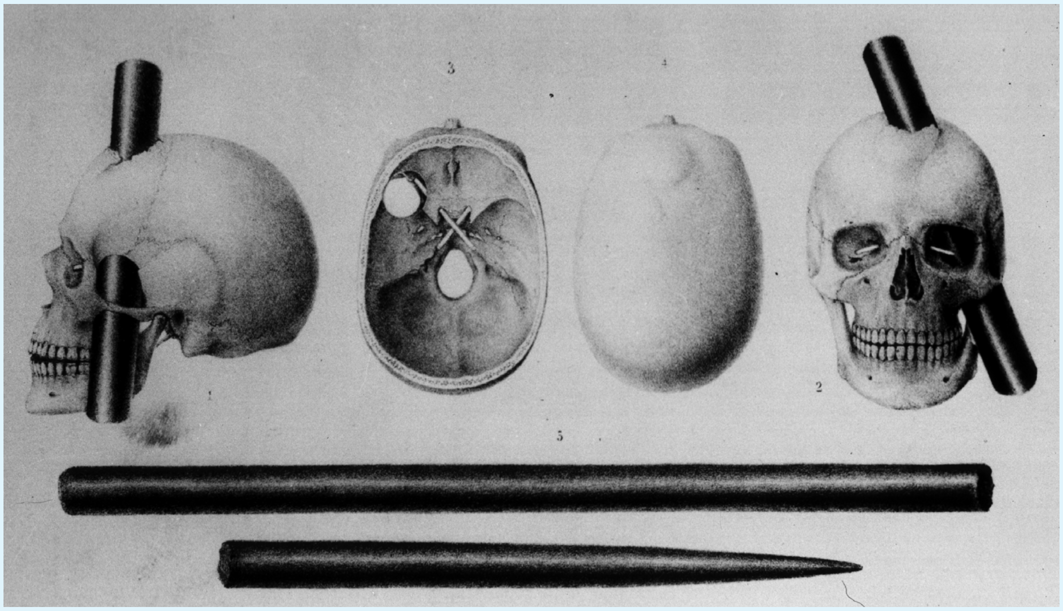

Figure 2-10 Phineas Gage.

Source: © National Library of Medicine.

The **temporal lobes** are located inferior to the posterior portion of the frontal lobes and inferior to the anterior portion of the parietal lobes (Figure 2-8). The temporal lobes house more memory than any other cerebral lobes. Most of the memory ability of the temporal lobes can be attributed to the hippocampi (plural). **Hippocampus** (singular) is Latin for *seahorse*. The hippocampi are located within the inferior and medial section of the temporal lobe where the cortex curls up into itself (**Figure 2-11**).

The hippocampi of the temporal lobes are so named because of their curled shape, which early anatomists thought resembled a *seahorse*. The hippocampal region takes new experiences and turns them into memories that can be stored and accessed later. Individuals who have damage to the hippocampal regions in both temporal lobes display severe to profound deficits in short-term memory because they cannot create new memories (Scoville & Milner, 1957), and long-term memory abilities might be destroyed as well. See the following Clinical Note about Patient H.M.

Hippocampus A region of the temporal lobe responsible for storing and creating memories. (Plural: hippocampi.)

Primary auditory cortex A region of cortex located within the temporal lobes responsible for receiving and processing neural impulses related to sound.

The **primary auditory cortex** is located on the superior temporal gyrus, anterior to Wernicke's area in the

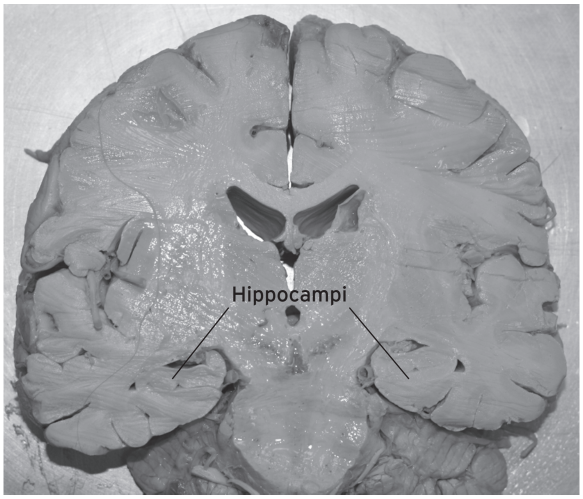

Figure 2-11 Hippocampi displayed on a coronal section of the brain.

left hemisphere (Figure 2-8). The primary auditory cortex is the section of the temporal lobes that first receives neural impulses of sound from the ears.

In the left temporal lobe, the left primary auditory cortex receives impulses of speech sounds and then passes these impulses on to Wernicke's area for processing so that, as mentioned earlier, the individual can comprehend spoken language. The right hemisphere's primary auditory cortex mostly passes impulses of environmental sounds and music to the area in the right hemisphere analogous to Wernicke's area (Bhatnagar, 2008) for the interpretation of meaning. Hence, the left hemisphere is responsible for auditory comprehension of verbal language while the right hemisphere is responsible for comprehension of the meaning of environmental sounds, such as a car starting or tree falling, as well as our appreciation of music.

Anterograde amnesia An inability to create new memories.

Occipital lobes The most posterior section of the cerebrum that is dedicated to receiving and processing neural impulses related to vision.

Clinical Note

Patient H.M.

The role of the hippocampus in creating new memories was brought to the attention of the medical community in the 1950s. A patient now known as H.M. was experiencing epileptic seizures to the point of being unable to work. Medications were ineffective in controlling his seizures (Scoville & Milner, 1957). Drastic action was considered to be warranted given H.M.'s severe epileptic condition. Dr. William Beecher Scoville decided to attempt a radical surgery on H.M.'s temporal lobes to relieve the patient of his seizures. Dr. Scoville removed sections of both H.M.'s temporal lobes extending into the hippocampal regions. This operation was performed in 1953 and was successful in relieving the patient of most of his seizures. However, an unexpected result of the surgery was a profound deficit in the ability to create new memories (Scoville & Milner, 1957). Although his memory of events prior to the surgery was mostly intact, Scoville and Milner (1957) report that 2 years after his surgery H.M. was still incapable of storing new information in his memory. This form of amnesia is known as **anterograde amnesia**. Scoville and Milner (1957) give some examples of the daily impact of H.M.'s memory deficit: After living in a new house for 10 months, H.M. still could not find his way around it; he would complete the same jigsaw puzzles and read the same magazines each day "without finding their contents familiar" (p. 14).

Although he possessed no conscious recollection of it, H.M. allowed a steady stream of scientists and students to study him and his memory continually throughout his life (Corkin, 2002). H.M.'s contribution to the understanding and science of memory and the brain is monumental. He also arranged for his brain to be exhumed for examination upon his death so that his case could continue to help others (Corkin, 2002). In 2008, Patient H.M., widely regarded as one of the most important individuals in the history of neuroscience, died at 82 years of age (Carey, 2008).

The **occipital lobes** are the most posterior of the cerebral lobes. They are located behind the parietal

Primary visual cortex The posterior-most section of the occipital lobes dedicated to receiving neural impulses of vision from the eyes.

and temporal lobes (Figure 2-8). The occipital lobes are concerned mostly with vision. The occipital lobes house the **primary visual cortex** (Figure 2-8), which receives visual information from the eyes. The primary visual cortex is located on the most posterior section of each occipital lobe. The right and left divisions of the primary visual cortex receive and process information from the contralateral visual field.

Just anterior to the primary visual cortex is the **visual association cortex** (Figure 2-8). This is the section of the brain that processes and interprets visual information received from the primary visual cortex allowing for appropriate visual perception (i.e., the visual association cortex allows people to make sense with the brain of what they are seeing with their eyes). This area performs much the same function for vision that Wernicke's area performs for spoken language. Just as a lesion at Wernicke's area creates a condition (an aphasia) in which the person might be able to hear spoken words but cannot deduce the meaning of the sounds, bilateral lesions at the visual association cortices often create a condition known as visual agnosia in which a person can see but cannot comprehend what she is seeing.

Subcortical Structures

Beneath the cortex is the **subcortex**, its name literally meaning *below the cortex*. Unlike the cortex, which is responsible for very high-level reasoning and cognitive abilities, the subcortex is responsible for performing functions that are more automatic and usually beneath the level of our awareness. Examples of subcortical functions are refining and monitoring motor plans, regulating automatic life-sustaining body functions such as heartbeat as well as automatic breathing, coordinating functions of the digestive system, and regulating level of arousal (this includes the sleep–wake cycle). The following subsections discuss four primary structures of the subcortex: the brain stem, cerebellum, thalamus, and basal ganglia.

Visual association cortex A section of cortex within the occipital-parietal region responsible for processing and interpreting visual information received from the primary visual cortex.

Subcortex The portion of the brain located beneath the cortex that deals less in reasoning abilities and higher-level cognition and more in autonomic, life-sustaining functions.

Brain stem A subcortical structure that connects the spinal cord to the rest of the brain and houses many structures involved in autonomic functions.

Medulla The superior-most section of the spinal cord that connects the spinal cord to the pons and is the site of decussation of a large portion of the motor tracts descending through the brain stem.

The Brain Stem

In evolutionary terms, the **brain stem** is the oldest part of the brain. As a species, we were sleeping, breathing, and mating long before we were enjoying Shakespeare or learning the Pythagorean theorem. Higher levels of cognition came only with the more recent evolution of the huge cerebrum that sits on top of our brain stems.

In a basic sense, the brain stem is the structure that connects the spinal cord to the brain. There are three main divisions of the brain stem. From top to bottom these are the midbrain, the pons, and the medulla (**Figure 2-12**). The **medulla** is the superior-most section of the spinal cord that connects the spinal cord to the pons. The medulla is the place where many of the motor fibers that transmit impulses of motor movement cross over or decussate to the other side of the body (**Figure 2-13**).

Because of the decussation of these motor fibers, the left side of the body is controlled by the right cerebral hemisphere and vice versa. Because of the decussation of these fibers, a lesion to the

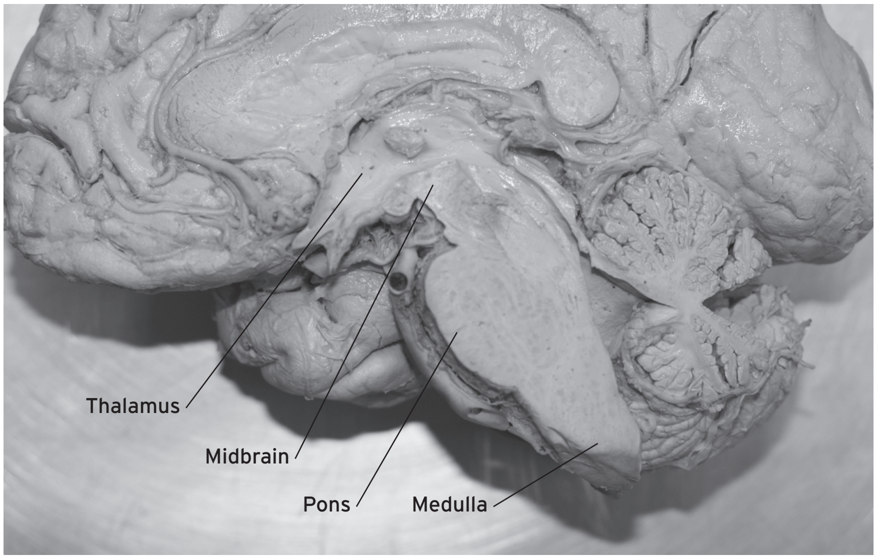

Figure 2-12 **Sections of brain stem shown in midsaggital section.**

descending motor tracts above the medulla creates a **hemiplegia** (one-sided paralysis) or a **hemiparesis** (one-sided weakness) on the side of the body contralateral (opposite) the lesion. If a lesion occurs below the level of decussation (such as within the spinal cord), the resulting hemiplegia or hemiparesis is on the side of the body ipsilateral (same) to the lesion.

Hemiplegia A unilateral spastic paralysis of the body.

Hemiparesis A unilateral spastic weakness of the body.

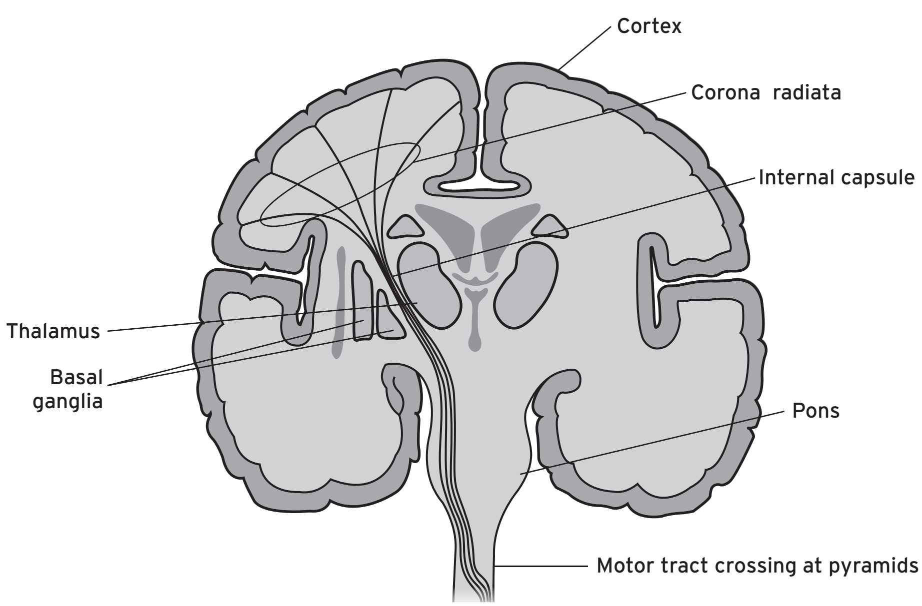

Figure 2-13 **Coronal section of the brain showing decussation of descending motor tracts at the level of the medulla.**

Pons The middle and slightly bulbous portion of the brain stem that provides an attachment between the cerebellum (not cerebrum) and the rest of the CNS.

Midbrain The superior-most section of the brain stem that houses the substantia nigra.

Substantia nigra A structure located within the midbrain responsible for the production of the neurotransmitter dopamine.

Reticular formation A series of nuclei stretching among the midbrain, pons, and medulla that regulates arousal, respiration, and blood pressure.

Located above the medulla is the pons (Figure 2-12). The **pons** is a slightly bulbous portion of the brain stem that provides an attachment between the cerebellum (not cerebrum) and the rest of the CNS. The pons also connects the medulla below to the midbrain above.

The superior-most section of the brain stem is the **midbrain** (Figure 2-12). The midbrain houses the substantia nigra. The **substantia nigra** is where the brain produces a neurotransmitter known as dopamine. When the substantia nigra fails to produce enough dopamine, the symptoms of Parkinson's disease begin to arise.

Stretching between the midbrain, pons, and medulla is a series of nuclei called the reticular formation or the reticular activating system. The **reticular formation** regulates arousal (i.e., level of wakefulness), respiration, and blood pressure (Seikel, King, & Drumright, 2010).

The Cerebellum

Hanging off the back of the brain stem under the occipital lobes is the cerebellum (**Figure 2-15**). The **cerebellum** is known as the *little brain* because of its resemblance to the cerebral hemispheres. The cerebellum resembles the cerebral hemispheres because it also is divided into right and left hemispheres (**Figure 2-14**), each with a tightly packed and folded gray matter layer superficial to white matter coursing below. These are the cerebellar hemispheres. Students must be sure not to confuse the cerebellar hemispheres with the cerebral hemispheres.

Cerebellum A subcortical structure hanging off the back of the pons and under the occipital lobes that is known as an error control device for body movement and ensures that body movements are smoothly coordinated and as error free as possible.

When cut through at midline in a saggital (front to back) fashion, the distinctive plant-like shape of the white matter fibers of the cerebellar hemispheres is apparent (Figure 2-15). This plant-shaped

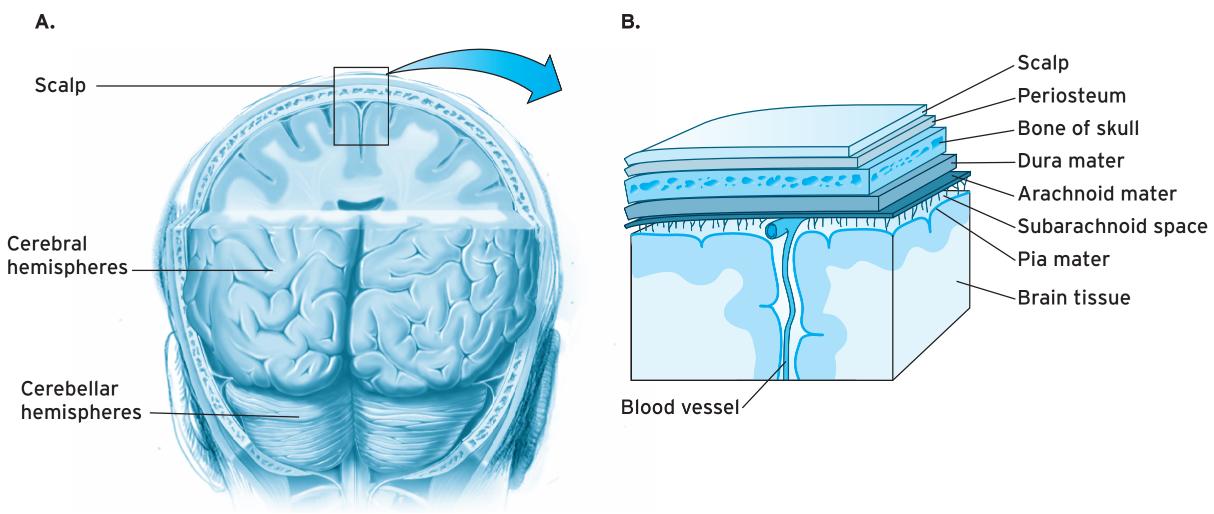

Figure 2-14 **A. The cerebellar and cerebral hemispheres. B. The meningeal layers.**

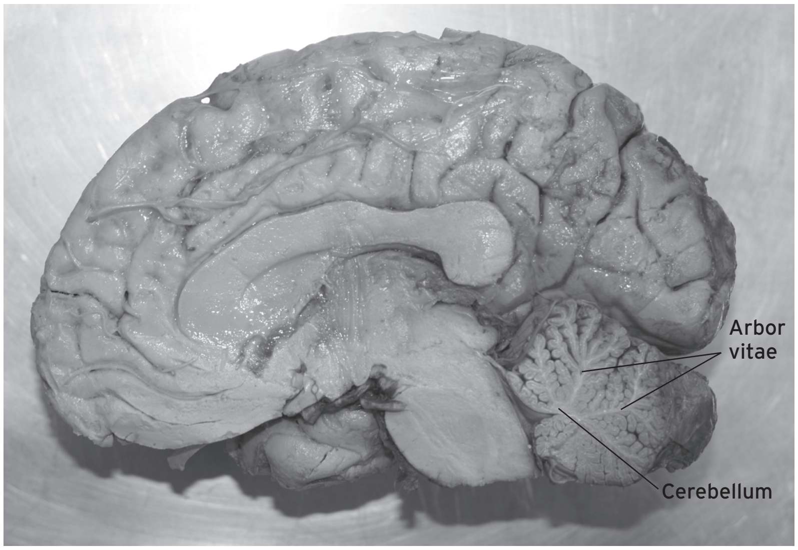

Figure 2-15 The cerebellum attached to the pons.

structure is known as the **arbor vitae** (Latin for *tree of life*). The right and left cerebellar hemispheres are connected to each other at midline by the unpaired vermis. The **vermis** is the midline gray matter that connects the cerebellar hemispheres and receives somatosensory information about the body through projections coursing through the pons.

Arbor vitae The distinctive plantlike shape of the fibers of the cerebellar hemispheres evident upon dissection and some imaging studies.

Vermis The midline gray matter that connects the two cerebellar hemispheres and receives somatosensory information about the body through projections coursing through the pons.

Peduncles Attachments between the cerebellum and the pons.

The cerebellum is attached to the pons and communicates with the rest of the CNS by the cerebellar **peduncles**. The word *peduncle* is used primarily to refer to the stalk that a piece of fruit hangs from. The word is used here because early anatomists perceived that the cerebellum resembled a piece of fruit hanging off the pons under the cerebrum. In order from top to bottom, there are three cerebellar peduncles: the superior, middle, and inferior cerebellar peduncles.

The cerebellum is known as an error control device for body movement. It makes sure that body movements are smoothly coordinated and error free. After motor plans are assembled in the primary motor cortex they are sent to the cerebellum to be checked for errors. The cerebellum monitors the intended movements of the motor plan and compares those plans with what the body is actually doing (Duffy, 2005). If there are any discrepancies between the motor plan and the body's execution of the motor plan, which are errors, the cerebellum makes corrections in the body's movements to match the motor plan to avoid the error. It does this by altering force, timing, and sequencing of muscle contractions (Diener & Dichgans, 1992). Although this discussion makes this process sound like it occurs in a step-by-step manner, the monitoring of the body's appropriate execution of motor plans by the cerebellum is an ongoing activity that continues in time as body movements continue.

Each cerebellar hemisphere receives and monitors motor plans from the contralateral cerebral hemisphere (Duffy, 2005). This means that motor signals from the left cerebral hemisphere are checked for errors in the right cerebellar hemisphere and motor signals from the right cerebral hemisphere are checked for errors in the left cerebellar hemisphere. Because of this arrangement each cerebellar hemisphere is responsible for monitoring movement occurring on the ipsilateral side of the body (Duffy, 2005).

Thalamus A subcortical structure that rests on top of the brain stem beneath the cerebrum and functions as a relay station for neural impulses of sensation (excluding olfaction).

Basal ganglia A group of subcortical structures located deep within the cerebral hemispheres on either side of the thalamus that works to regulate body movement.

Spinal cord A bundle of white matter tracts and gray matter housed within the bony vertebral column that enables afferent (sensory) impulses coming from the body to be transmitted to brain and efferent (motor) impulses from the brain to be transmitted to the body.

The more rapid and precise a body movement is, the greater the likelihood that an error in the execution of motor plans will occur and the harder the cerebellum will work to minimize that risk. For example, as a professional pianist performs a complicated piece, the cerebellum works much harder to monitor for errors the motor plans of finger movements than it does if the pianist simply waved her arm in the air. A far more common activity that also requires a great deal of rapidity and precision in motor execution and that is used by almost everyone every single day is speech. Because the act of producing smoothly articulated speech requires a great deal of cerebellar input, difficulties in articulation can be a first indicator of cerebellar pathology. Pathology of the cerebellum often produces a speech problem known as ataxic dysarthria.

The Thalamus

The **thalamus** sits on top of the brain stem and under the cerebral hemispheres (Figure 2-12, Figure 2-13). This is a perfect location for the thalamus because the thalamus is responsible for taking sensory signals from one part of the nervous system and directing them to another part of the nervous system. The tag line associated with the thalamus is that it is a *relay station*. Specifically, all afferent (sensory) information (excluding olfaction) passes through the thalamus before arriving at the correct portion of the cerebral cortex for processing. For example, the optic nerve from the eyes passes through the thalamus on its way to the occipital lobes. Afferent impulses of proprioception and taction coming up from the body pass up the spinal cord, through the brain stem, and through the thalamus to the primary sensory cortex in the parietal lobes. The thalamus also takes the motor plans that the cerebellum has checked for errors and sends those motor plans to the appropriate places for execution (Duffy, 2005).

The Basal Ganglia

The term *ganglia* refers to a collection of nerve cells. The **basal ganglia** is a group of subcortical structures located deep within the cerebral hemispheres on either side of the thalamus (Figure 2-13). The structures of the basal ganglia include the caudate nucleus, the putamen, and the globus pallidus (Duffy, 2005). These structures have complex circuitry and interconnections among themselves and other portions of the CNS. The basal ganglia and its connections and circuitry are far from being perfectly understood. Nonetheless, it is clear that the basal ganglia play a strong role in motor movement. Lesions to the basal ganglia create problems with initiation of movement, muscle tone, and extra movements. These are all the symptoms of Parkinson's disease, which is created by dysfunction of the basal ganglia. Parkinson's disease occurs when the substantia nigra fails to produce dopamine, which the basal ganglia requires to operate properly.

The Spinal Cord

The **spinal cord** is a bundle of white matter tracts and gray matter housed within the bony vertebral column. It allows afferent (sensory) impulses coming from the body to be transmitted to brain and efferent (motor) impulses from the brain to be transmitted to the body.

The spinal cord originates superiorly at the medulla. The spinal cord then passes inferiorly through the vertebral column until it narrows at a section known as the conus medullaris. The spinal cord terminates inferiorly at the **conus medullaris** in the lumbar region of the lower back. Below the level of the conus medullaris the spinal cord breaks up into loose strands of spinal nerves called the **cauda equina**, or *horse's tail*, so named because of the resemblance of the loose strands of nerves to the hairs of a horse's tail (Figure 2-16).

Conus medullaris Conical point of inferior termination of the spinal cord in the lumbar region of the lower back.

Cauda equina The loose strands of spinal nerves that separate from the inferior termination of the spinal cord.

In a cross section or transverse cut of the spinal cord, a gray butterfly or H shape appears in the middle (Figure 2-17). The grayness of the butterfly shape stands out in contrast to the whiteness of the surrounding tissue. This gray tissue is spinal nerve matter and can be thought of as the location where the spinal nerves enter and leave the spinal cord. The topmost wings of the butterfly shape are known as the dorsal horns. The nerve cells of the dorsal horns deliver the sensory (afferent) information from the spinal nerves to the surrounding white matter tracts to be transmitted to the brain. The bottom wings of the butterfly shape are known as the ventral horns. The nerve cells of the ventral horns deliver motor (efferent) information from the associated white matter tracts in the spinal cord to the spinal nerves to be delivered to the organs and muscles. In the usual orientation of the spinal cord within the vertebral column the dorsal horns point posteriorly while the ventral horns point anteriorly.

Figure 2-16 Cauda equina of the spinal cord.

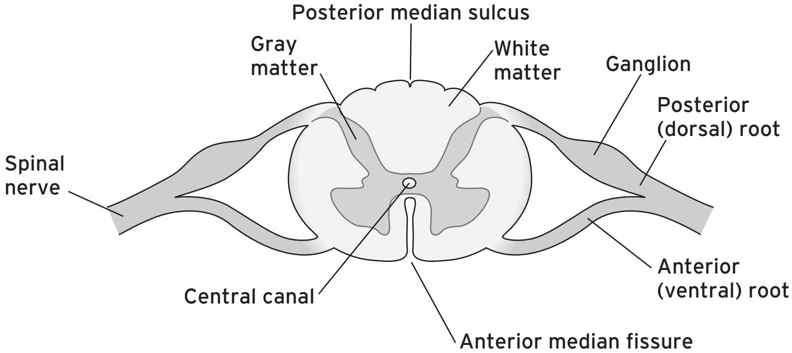

Figure 2-17 Cross section of spinal cord.

In addition to being a major highway between the brain and body for afferent and efferent signals, the spinal cord is also involved in basic reflexes. A **reflex** is the production of a physical movement that occurs automatically in response to a stimulus and is initiated below the level of awareness. Perhaps the most salient example of a reflex is the pain withdrawal reflex. Accidentally laying a hand on a hot stove produces this reflex: When a person's hand touches the hot surface, he pulls his hand away from the stove very quickly. In fact, he begins pulling the hand away before he realized his hand was being burned or that he was even in pain. In other words, the rest of this person's CNS does not wait for the cerebral cortex (which is the portion of the CNS farthest away from the burning hand) to realize the hand is burning before deciding to get it off the hot stove. This is a survival mechanism that allows people to react much faster than they would be able to if they had to wait for the sensation of pain to travel all the way up to the cerebral cortex, which is the farthest section of the CNS from the extremities.

Reflex The production of a physical movement that occurs automatically in response to a stimulus and is initiated below the level of awareness.

Stretch reflex A contraction of a muscle in response to a passive stretching of a muscle spindle within a muscle. This reflex enables the body to correct any unintended changes in body position in a timely manner without waiting for input from the cerebral cortex as well as keep appropriate tone in the muscles.

One very important reflex of concern to speech-language pathologists is the **stretch reflex**. The most well known example of this is the kick a leg makes unintentionally after the knee is tapped, the patellar reflex. When a doctor taps an individual's knee, she is momentarily stretching a muscle in the person's leg. A sensory receptor in that muscle called a muscle spindle is stretched as well and sends an afferent signal to the spinal cord indicating that the muscle has moved. The spinal cord receives this signal and recognizes that the leg muscle has been moved and yet no instructions came down from the brain telling that muscle in the leg to do so. The spinal cord knows that it is problematic for a body part to be moving with no commands from the brain to do so.

The spinal cord here is a mediator between the body and the brain. The spinal cord monitors the motor plans for the muscles as they come down from the brain, and then it sends those motor plans out along the cranial and spinal nerves to the muscles for execution. When a muscle behaves in a way contradictory to the motor plans sent down from the brain, the spinal cord is the first to know. It is problematic for survival if a person's muscles or body parts are not where the brain wants them to be and doing what the brain has told them to do. In evolutionary terms, this could mean the difference between a narrow escape with a saber-tooth tiger or a saber-tooth tiger tearing off an arm. Fortunately, the spinal cord doesn't wait for information concerning this discrepancy to travel all the way up to the cerebral cortex and rise to the level of conscious awareness. It recognizes the situation as an emergency and takes immediate action without consulting the brain.

Now back to the knee. When a muscle is lengthened passively, as when a doctor tests the patellar reflex, the spinal cord recognizes the discrepancy between the motor plans sent by the brain and the afferent signal coming from the muscle informing the spinal cord that the muscle has moved out of place (i.e., the spinal cord recognizes that no signal came from the brain telling the muscle that just moved to move). The spinal cord then originates and sends its own efferent (motor) signal out to the muscle to correct the situation and contract the muscle into its original and intended position. This contraction causes the leg to kick in response to the tap on the knee. In short, before the brain realizes there is a problem the spinal cord steps in and tells the offending muscle or body part to get to where it is supposed to be to correct the situation.

Normally, the stretch reflex is a good thing. In healthy individuals, the stretch reflex allows their bodies to correct any unintended changes in body position in a timely manner without waiting for input from the cerebral cortex as well as keeps appropriate tone in the muscles. However, the stretch reflex can be problematic when it becomes hyperactive. In some clinical scenarios, the spinal cord overapplies the stretch reflex and uses this hyperactive stretch reflex to create hypertonia in affected musculature which, combined with the weakness discussed previously, inhibits the individual's ability to move the affected body parts. This overactive stretch reflex also resists passive muscle movement. In these cases, a person's muscles might tighten, accomplish volitional movement with difficulty, and be resistant to movement when the clinician attempts to passively move the affected limbs or musculature. This resistance to passive movement brought about by an overactive stretch reflex is a big part of producing spasticity in musculature.

Spasticity is a combination of hypertonia (overtightness of muscles) and the resistance to passive movement caused by a hyperactive stretch reflex that makes movement of a body part difficult (i.e., it creates a spastic weakness). A clinical example is spastic cerebral palsy. Spastic cerebral palsy is the most common form of cerebral palsy and can be mild, affecting only a single extremity, or severe enough to affect an individual's entire body. If an individual's laryngeal, oral, or thoracic musculature is spastic, then the ability to move those structures is weakened, which can affect production of speech. This communication disorder is termed spastic dysarthria and occurs as a result of bilateral damage to motor tracts within the CNS usually by stroke.

Spasticity A combination of hypertonia and the resistance to passive movement caused by a hyperactive stretch reflex that makes movement of a body part difficult.

Blood Supply to the Brain

Although the average human brain is only about 2% of total body weight, the brain consumes between 20% and 25% of the total amount of oxygen and glucose used by the body. In other words, up to a fourth of the body's oxygen and energy supplies is used to power this single organ. Any interruption of blood flow to the brain, such a stroke, has immediate and possibly dire consequences. To keep up the supply of blood to the brain necessary to meet these massive requirements the body must get blood first from the heart to the head.

The two pairs of large arteries whose function it is to deliver blood superiorly to the brain to be distributed throughout the brain by other arteries are the internal carotid arteries and the vertebral arteries. The paired right and left **internal carotid arteries** course superiorly from the thorax in the anterior portion of the neck (**Figure 2-18**). The pulse in the neck is felt by palpating the internal carotid. The internal carotid arteries course through the neck to the base of the brain to link with the **circle of Willis**. Once the internal carotid arteries reach the circle of Willis, the paired left and right anterior cerebral arteries and middle cerebral arteries branch off from the internal carotids (**Figure 2-19**). The **anterior cerebral arteries** course anteriorly to supply blood to the frontal and parietal lobes, basal ganglia, and corpus callosum (Seikel et al., 2010). The **middle cerebral arteries** course laterally to supply blood flow to Broca's area, Wernicke's

Internal carotid arteries Paired arteries that course superiorly from the thorax within the anterior portion of the neck to the base of the brain to link with the circle of Willis.

Circle of Willis A series of anastomoses that connects the internal carotid and vertebral/basilar system, acts to ensure equal blood flow to all areas of the brain, and acts as a safety valve if an occlusion occurs within the circle of Willis or below the circle of Willis.

Anterior cerebral arteries Paired arteries that originate from the internal carotid arteries at the circle of Willis and course anteriorly to supply blood to the frontal and parietal lobes, basal ganglia, and corpus callosum.

Middle cerebral arteries Paired arteries that originate from the internal carotid arteries at the circle of Willis and course laterally to supply blood flow to Broca's area, Wernicke's area, the temporal lobes, and the primary motor cortex.

Vertebral arteries Paired arteries that course superiorly through the cervical vertebrae of the spinal column in the posterior aspect of the neck and come together to form the basilar artery at the pons.

Basilar artery A single unpaired artery that joins the circle of Willis posteriorly and branches into the paired posterior cerebral arteries.

Posterior cerebral artery Paired arteries that branch off the basilar artery at the circle of Willis to course posteriorly and deliver blood to the occipital lobes, cerebellum, and the inferior temporal lobes.

Anastomosis A connection between blood vessels. (Plural: anastomoses.)

Anterior communicating artery An unpaired anastomosis between the right and left anterior cerebral arteries that forms the anterior portion of the circle of Willis.

Posterior communicating arteries Paired anastomoses coursing from the left posterior cerebral artery to the left middle cerebral artery and also coursing from the right posterior cerebral artery to the right middle cerebral artery.

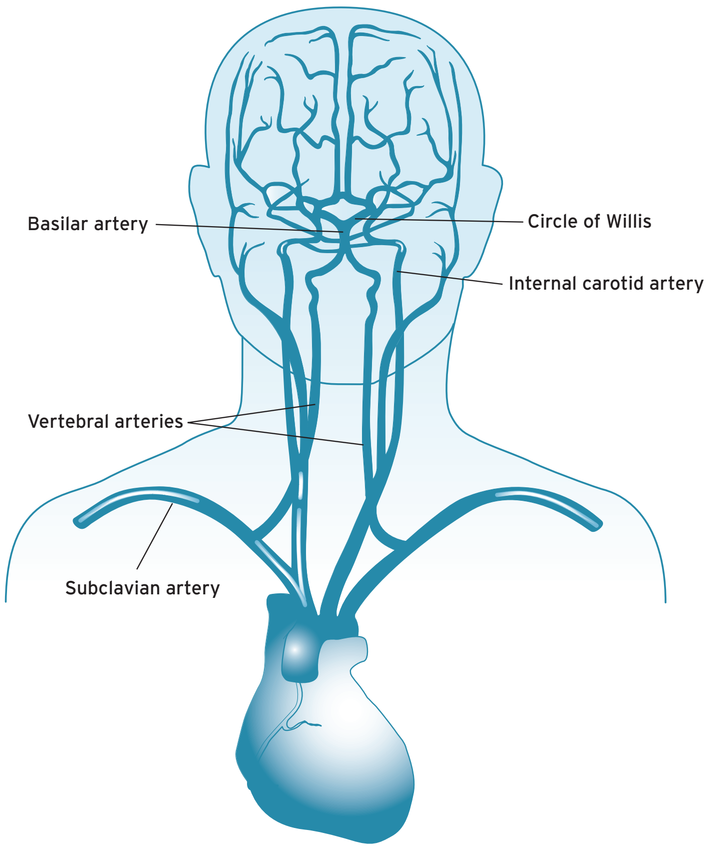

Figure 2-18 Major arteries supplying blood flow to the brain.

area, the temporal lobes, and the primary motor cortex.

Meanwhile, the paired right and left **vertebral arteries** course superiorly through the cervical vertebrae of the spinal column in the posterior aspect of the neck (Figure 2-18). The vertebral arteries come together to form the basilar artery at the pons. The **basilar artery** then proceeds to join to the posterior section of the circle of Willis (Figure 2-19). Once the basilar artery reaches the circle of Willis, it branches into the **posterior cerebral arteries** (Figure 2-19), which delivers blood to the occipital lobes, cerebellum, and the inferior temporal lobes (Seikel et al., 2010).

The circle of Willis is a set of **anastomoses** (i.e., connections between arteries) between the anterior, middle, and posterior cerebral arteries that together form a circle at the base of the brain. The **anterior communicating artery** connects the left and right anterior cerebral arteries. The **posterior communicating arteries** link the posterior cerebral arteries to the middle cerebral arteries.

The circle of Willis is highly important because by connecting the internal carotid and vertebral/basilar systems it acts to ensure equal blood flow to all areas of the brain and acts as a safety valve if an occlusion

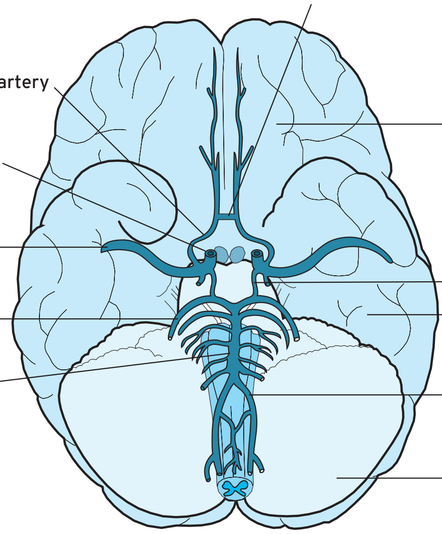

Figure 2-19 Circle of Willis.

(i.e., a clot) occurs within the circle of Willis or below the circle of Willis. For instance, if there is a sudden reduction in blood flow from the left internal carotid artery, blood can course through communicating arteries from the basilar and right internal carotid arteries to sustain blood flow to those areas of the brain dependent on the internal carotid artery for blood supply. In this way, brain tissue can be saved from oxygen deprivation and tissue death.

The Peripheral Nervous System

The PNS is composed of the nerves that connect the CNS to the rest of the body. These nerves can be thought of as wires that connect at one end to a muscle, organ, or gland and at the other end to the brain, brain stem, or the spinal cord.

Efferent signals from the brain travel along the PNS to reach the muscles to command them to move. Examples of efferent information sent from the CNS are commands to muscles to contract or relax to move a body part or to make the heart beat as well as commands regulating body metabolism.

Afferent signals originating with the body are transmitted along the PNS on their way back to the CNS for processing. Afferent information is analyzed and interpreted by the CNS in the cerebrum. For example, the sensory information about the way an individual feels following striking his thumb with a hammer is transmitted along the nerves of the PNS to the CNS where that afferent signal is processed and understood as pain.

The two primary divisions of the PNS are the cranial nerves and spinal nerves.

The Spinal Nerves

As their name implies, **spinal nerves** are associated with the spinal cord. Whereas the cranial nerves contribute to control of the head and neck, the spinal nerves contribute to control of the rest of the body. The spinal cord and spinal nerves are associated with movement and control of the trunk of the body and the arms and legs. There are 31 pairs of spinal nerves. Each spinal nerve arises within the gray matter of the spinal cord and then courses out from

Spinal nerves Nerves that course between the spinal cord and the body.

between the 33 individual bones of the vertebral column (the vertebrae) to innervate the body (Figure 2-17). Each spinal nerve connects the spinal cord to a muscle, organ, or gland of the body.

Most spinal nerves do not play a direct role in speech. However, the **phrenic nerve** innervates the diaphragm. The **diaphragm** is the muscle that is primarily responsible for the inspiration of air into the lungs. Of course, respiration is necessary to life, but it also is essential for the production of phonation for speech.

The Cranial Nerves

As their name implies, the **cranial nerves** are associated with the cranium. The cranium is the bony part of the skull that encases and protects the brain. The cranial nerves connect muscles and structures of the head, face, and neck to the CNS. There are 12 cranial nerves. Each of the cranial nerves is a paired nerve, meaning that there is one for the right side of the body and an analogous one for the left side of the body.

Thorough knowledge of the function and location of the cranial nerves is a powerful diagnostic tool for the speech-language pathologist. Based on the presence of certain speech, voice, or swallowing difficulties, a speech-language pathologist often can discern the presence of pathology in the PNS and, using knowledge of the function of the cranial nerves, can determine with which nerve(s) the problem originates.

The cranial nerves are numbered by roman numerals in the order that they synapse, or connect, to the CNS from superior to inferior. The olfactory nerve is numbered I because, from superior to inferior, it is the first cranial nerve to synapse with the CNS. In contrast, the hypoglossal nerve is XII because the other 11 cranial nerves attach to the portions of the brain and brain stem above it.

The cranial nerves are all either motor nerves, sensory nerves, or mixed sensory-motor. Cranial nerves that are motor in nature carry only efferent impulses from the CNS out to the body. Those that are sensory in nature transmit only afferent impulses from the body back to the CNS. The cranial nerves that function both as sensory and motor nerves relay both efferent and afferent information between the CNS and the body. See **Table 2-1** for a complete listing of the cranial nerves and their function.

Although all the cranial nerves are very important to know, this book focuses on those whose function is important for communication. The cranial nerves that are most directly important to speech are trigeminal V, facial VII, glossopharyngeal IX, vagus X, accessory XI, and hypoglossal XII.

The Trigeminal V

The fifth cranial nerve, the trigeminal, is one of the largest cranial nerves and one of the most important cranial nerves for speech (see **Figure 2-20**.) It is a mixed motor and sensory nerve. The trigeminal emerges from the pons and splits into three primary branches: the **ophthalmic branch**, the **maxillary branch**, and the **mandibular branch** (Seikel et al., 2010). The ophthalmic branch is sensory in nature

Phrenic nerve A spinal nerve that provides innervation to the diaphragm.

Diaphragm The primary muscle of inspiration.

Cranial nerves Nerves that course between the brain stem and the head/neck/face and are either motor/efferent, sensory/afferent, or mixed sensory-motor in function.

Ophthalmic branch A branch of the trigeminal nerve that is sensory in nature and transmits afferent information from the upper face, forehead, and scalp to the central nervous system.

Maxillary branch A branch of the trigeminal nerve that is sensory in nature and is responsible for transmitting afferent information from the teeth, upper lip, buccal and nasal cavities, as well as the sides of the face to the CNS.

Mandibular branch A branch of the trigeminal nerve with both sensory and motor functions. The afferent portion of this nerve carries sensory information from the lower teeth, lower gums, bottom lip, as well as somatic information from portions of the tongue. The efferent component innervates muscles of mastication.

Table 2-1 Cranial Nerves

Roman Numeral	Cranial Nerve	Origin	Type	Function
I	Olfactory	Cerebral hemispheres	Sensory	Smell
II	Optic	Thalamus	Sensory	Vision
III	Oculomotor	Midbrain	Motor	Movement of the eyes
IV	Trochlear	Midbrain	Motor	Movement of the eyes
V	Trigeminal*	Pons	Sensory	Somatic sensation from face, lips, jaw
			Motor	Movement of the mandible
VI	Abducens	Pons	Motor	Movement of the eyes
VII	Facial*	Pons	Sensory	Gustation (taste) from the anterior two-thirds of the tongue
			Motor	Movement of the lips and face
VIII	Cochleovestibular	Pons, medulla	Sensory	Hearing and balancing
IX	Glossopharyngeal*	Medulla	Sensory	Gustation (taste) from the posterior one-third of the tongue
			Motor	Movement of superior portion of pharynx
X	Vagus*	Medulla	Sensory	Sensation from larynx, pharynx, abdominal viscera
			Motor	Movement of the larynx, pharynx, velum
XI	Accessory*	Medulla, spinal cord	Motor	Movement of the muscles of shoulder and neck (trapezius)
				Assisting vagus on movement of the larynx, pharynx, and velum
XII	Hypoglossal*	Medulla	Motor	Movement of the tongue

* Necessary for speech production.

and transmits afferent information from the upper face, forehead, and scalp to the CNS (Figure 2-20). The maxillary branch is also a sensory nerve and is responsible for transmitting afferent information from the teeth, upper lip, buccal and nasal cavities, as well as the sides of the face to the CNS (Figure 2-20). In contrast, the mandibular branch has both sensory and motor functions. The afferent portion of this nerve carries sensory information from the lower teeth, lower gums, and bottom lip and somatic information from portions of the tongue (Figure 2-20). The efferent component of the mandibular branch of the trigeminal nerve innervates muscles of mastication. For an interview with an individual regarding pathology of the trigeminal refer to the video *Trigeminal Neuralgia*.

The Facial Nerve VII

The seventh cranial nerve, the facial, is a mixed sensory-motor nerve. The facial nerve emerges from the inferior pons. The primary motor function of the facial nerve is to provide motor innervation to the muscles of the face. The primary sensory function of the facial nerve is to transmit afferent information concerning taste from the anterior two-thirds of the tongue to the CNS (Gertz, 2007).

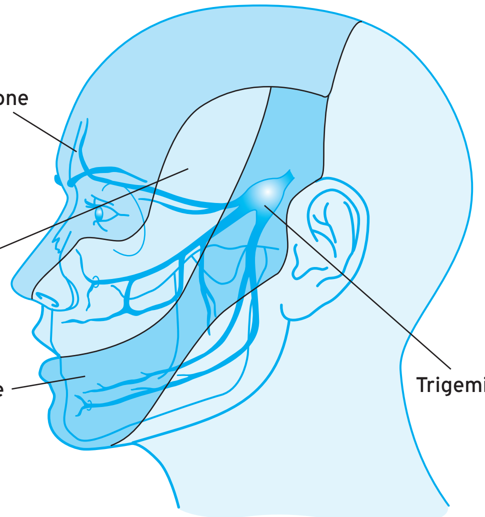

Figure 2-20 Areas of the face and scalp innervated by the Mandibular, Maxillary, and Opthalmic branches of the trigeminal nerve.

The facial nerve has four branches. From superior to inferior these are the temporal branch, the zygomatic branch, the buccal branch, and the mandibular branch. A distinctive feature of the facial nerve is that the temporal and zygomatic branches, which innervate the muscles of the upper face, receive plans of volitional motor movement for the upper face from the contralateral *as well as* the ipsilateral cerebral hemispheres (Figure 2-21). When one side of a paired nerve (the right or the left) receives motor plans from both the right and left cerebral hemispheres, it is termed **bilateral innervation**.

In contrast, the inferior branches of the facial nerve, the buccal and the mandibular branches, which innervate the muscles of the lower face, are unilaterally innervated. **Unilateral innervation** of a nerve indicates that the nerve receives motor plans from only the contralateral cerebral hemisphere. More simply: The muscles of each side of the upper face receive motor plans from both the right cerebral hemisphere and the left cerebral hemisphere (Figure 2-21). So, when an individual moves one side of her upper face and forehead, those motor plans come from both cerebral hemispheres. However, the muscles of either side of the lower face receive motor plans only from the contralateral cerebral hemisphere (Figure 2-21). Therefore, when an individual twitches the right side of her mouth, that motor plan comes only from the left cerebral hemisphere.

Other cranial nerves besides the facial nerve are also bilaterally innervated, though sometimes inconsistently between individuals. The facial nerve presents a unique opportunity to learn unilateral and bilateral innervation because the superior branches receive bilateral innervation whereas the inferiorly located branches receive only unilateral innervation.

There is a **protective redundancy** in bilateral innervation. With bilateral innervation, a lack of motor

Bilateral innervation An innervation pattern that occurs when one side of a paired nerve (the right or the left) receives motor plans from both the right and left cerebral hemispheres.

Unilateral innervation An innervation pattern that occurs when a nerve receives motor plans from only the contralateral cerebral hemisphere.

Protective redundancy When the body duplicates systems to protect proper functioning.

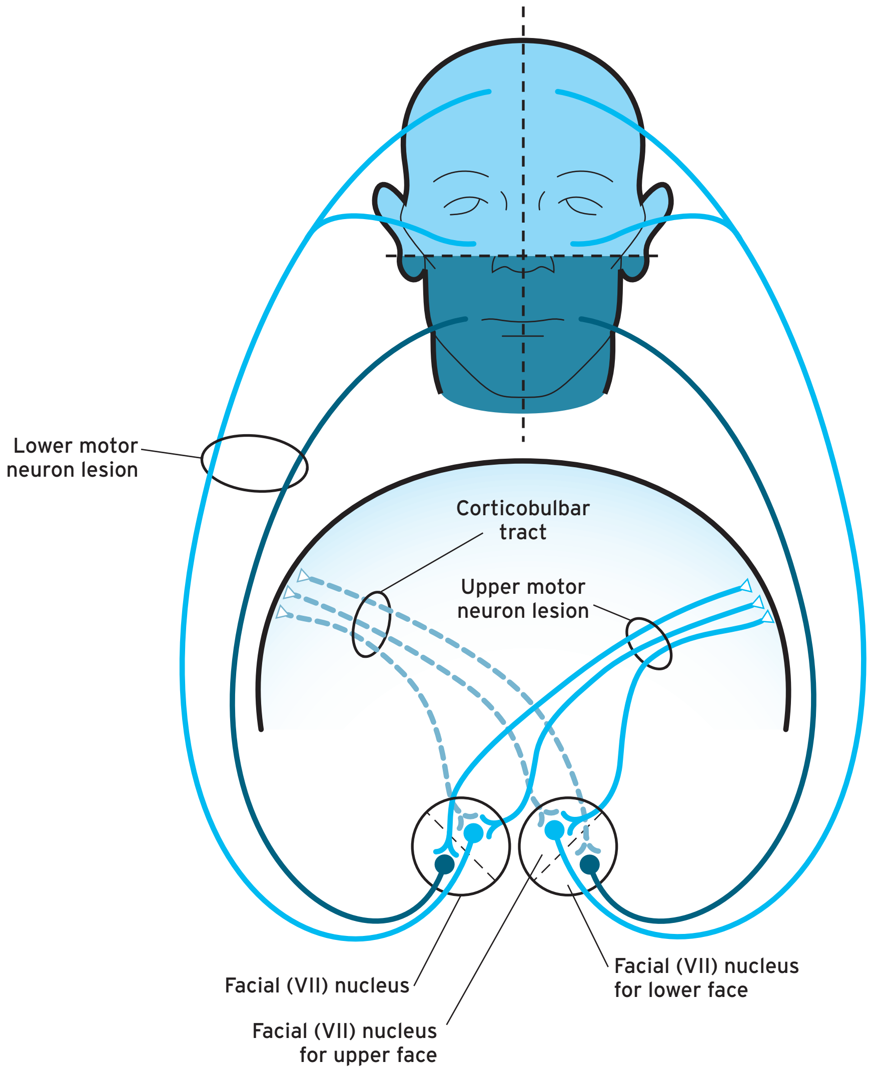

Figure 2-21 Bilateral innervation of the facial nerve.

plans coming from one cerebral hemisphere does not completely incapacitate a body part if that body part can still receive motor plans from the opposite hemisphere. So, why is this important? Take the phrenic nerve, which innervates the diaphragm, for example. The diaphragm is the primary muscle for respiration and the phrenic nerve, which supplies motor commands to the diaphragm, is bilaterally innervated. If the phrenic nerve was not bilaterally innervated, then damage to one cerebral hemisphere would incapacitate the entire contralateral half of the diaphragm. However, due to the protective redundancy of bilateral innervation, an individual can suffer damage to a cerebral hemisphere and still retain some function in the contralateral portion of the diaphragm. Because moving the diaphragm is important to sustaining life, the significance of bilateral innervation becomes evident. Figure 2-21 shows an illustration of the bilateral innervation of the superior portions of the facial nerve.

Glossopharyngeal IX

The ninth cranial nerve, the glossopharyngeal, has both sensory and motor functions. The primary sensory function of the glossopharyngeal is transmitting taste from the posterior one-third of the tongue and also from a portion of the soft palate. The motor function of the glossopharyngeal nerve is to deliver efferent signals to the superior muscles of the pharynx, which are involved in swallowing, as well as to the parotid gland, which produces saliva (Gertz, 2007).

Vagus X

The 10th and largest cranial nerve, the vagus, is perhaps the most important cranial nerve for the speech-language pathologist. The vagus is a long and complex nerve with both sensory and motor functions. The vagus exits the medulla and travels inferiorly to innervate the muscles of the soft palate, pharynx, and larynx. Figure 2-22 is an illustration of the sections of the vagus.

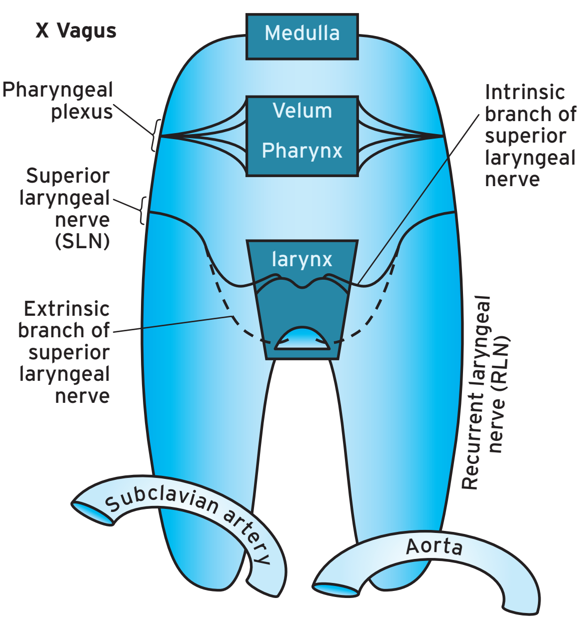

Figure 2-22 Sections of the vagus nerve.

Upon leaving the medulla, the first branch of the vagus innervating a structure important for speech is the pharyngeal plexus. This branch of the vagus innervates most of the muscles of the inferior pharynx as well as most of the muscles of the velum. The muscles of the inferior pharynx are responsible for pharyngeal constriction, which is used during swallowing, while the muscles of the velum are important for sealing off the nasal cavity for production of nonnasal phonemes and also for avoiding nasal regurgitation during swallowing.

Continuing inferiorly, the second branch of the vagus important for speech is the superior laryngeal branch, or the superior laryngeal nerve (SLN). The SLN has an intrinsic and an extrinsic branch. The intrinsic branch of the SLN is sensory in nature and responsible for transmitting sensory information from the inside of the larynx to the CNS. The extrinsic portion of the SLN is responsible for innervating the cricothyroid muscle (the primary tensor of the vocal folds).

The vagus then courses and passes inferiorly into the thorax. The right vagus nerve passes under the right subclavian artery within the right side of the thorax. The left vagus passes under the arch of aorta of the heart within the left side of the thorax. Both of these branches then immediately change course and pass superiorly back, *recurring*, into the neck and to the larynx to innervate all the remaining intrinsic muscles of the larynx (those muscles responsible for adduction and abduction of the vocal folds). These branches of the vagus are known appropriately as the recurrent laryngeal nerve (RLN).

Accessory XI

The 11th cranial nerve, the accessory, is an efferent nerve and as such is only motor in function. The accessory nerve has a spinal component responsible for innervating muscles of the shoulders such as the trapezius, but also has a cranial component. The cranial component of the accessory nerve and the functional differences between it and the vagus nerve are poorly understood. The cranial component of the accessory nerve works alongside the vagus (as an accessory). The spinal component of the accessory nerve innervates some of the muscles of the shoulders.

Hypoglossal XII

The 12th and last cranial nerve is the hypoglossal. The hypoglossal nerve exits the brain stem at a more inferior location off the medulla than any other cranial nerve. The hypoglossal nerve is motor in nature. The primary role of the hypoglossal nerve is to innervate all the intrinsic muscles of the tongue and most of the extrinsic muscles of the tongue. The intrinsic muscles of the tongue are the muscles that comprise the actual body of the tongue and are responsible for the more fine motor movements of the tongue involved in articulation. The extrinsic muscles of the tongue are those muscles responsible for gross movements of the tongue, such as the extension and retraction of the tongue. These gross motor movements of the tongue are more likely to be used during mastication and swallowing than during speech.

Main Points

- The nervous system is divided into the central nervous system (CNS), which is made up of the brain and spinal cord, and the peripheral nervous system (PNS), which is made up of the cranial nerves and spinal nerves.
- The brain is grossly composed of the cerebrum, brain stem, and cerebellum.
- The surface of the cerebrum is the cerebral cortex and is composed of folded tissue that creates gyri and sulci. These folds of cortical tissue enable more neural tissue to be packed into a smaller space.
- The brain is made up of gray and white matter. Gray matter lacks myelin, a fatty substance used to facilitate the conduction of electrical impulses along tracts of white matter. Gray matter is responsible for processing information. White matter is responsible for transmitting information. White matter is made up of three types of fibers. These include association fibers, commissural fibers, and projection fibers.
- The cerebrum is divided into right and left cerebral hemispheres by the longitudinal fissure. The right and left cerebral hemispheres are connected by a thick band of commissural fibers called the corpus callosum.
- The right cerebral hemisphere is responsible for the interpretation of nonlinguistic stimuli such as facial expressions, body language, gestures, prosody, melody, rhythm, and environmental sounds; understanding macrostructure; visuospatial processing; and attention (sustained and selective).
- The left cerebral hemisphere is primarily responsible for expressive and receptive language abilities. Broca's area is primarily responsible for expressive language, and Wernicke's area is primarily responsible for receptive language.
- The cerebrum is divided into four paired lobes: frontal, parietal, temporal, and occipital. The frontal lobes' functions include expressive and receptive language, as well as motor movements. The parietal lobes' functions include receiving and processing sensory information regarding the body such as taction and proprioception. The temporal lobes' functions include memory

as well as receiving and processing auditory information through the primary auditory cortices. Last, the occipital lobes' functions include receiving afferent signals of vision as well as processing visual information.

- The frontal and parietal lobes are divided by the central sulci, which run laterally down the side of each cerebral hemisphere in a vertical fashion. The frontal and parietal lobes are divided from the temporal lobes by the lateral sulci, which run anteriorly to posteriorly at an upward angle through each cerebral hemisphere.
- Structures of the subcortex are the brain stem, cerebellum, thalamus, and basal ganglia. The subcortex is responsible for less volitional and more automatic/visceral functions such as heartbeat, breathing, and sleep–wake cycles.
- The brain stem is composed of (from superior to inferior) the midbrain, pons, and medulla. The brain stem connects the spinal cord to the brain.
- The cerebellum is made up of two hemispheres connected by the vermis at midline. The cerebellum is attached to the pons by the inferior, medial, and superior peduncles. The cerebellum is as an error control device and works to create smoothly coordinated and errorless body movements.
- The thalamus rests on top of the brain stem and is the relay station for afferent signals.
- The basal ganglia is made up of the caudate nucleus, putamen, and globus pallidus and is responsible for regulation of motor movement, muscle tone, and inhibition of extraneous movements.
- The spinal cord, which begins at the medulla, narrows and terminates at the conus medullaris and divides into in loose strands of nerves. The spinal cord transmits afferent information from the PNS to the brain and transmits efferent information from the brain to the PNS. The spinal cord is also responsible for originating the stretch reflex, which can become hyperactive in certain pathologic situations, such as damage to the motor pathways within the CNS, and result in spasticity.
- The brain consumes 25% of all oxygen and glucose brought into the body.
- The internal carotid arteries and the basilar artery transmit blood from the thorax to the brain.
- The anterior cerebral arteries, middle cerebral arteries, and posterior arteries transmit blood out to certain portions of the brain.
- The anterior communicating artery and the posterior communicating arteries link up the internal carotid system with the vertebral/basilar system to form the circle of Willis. The circle of Willis acts as a safety valve to protect the brain from a lack of blood supply.
- The 31 paired spinal nerves connect the spinal cord to muscles, organs, and glands that usually do not play a direct role in speech production. However, the phrenic nerve is a spinal nerve that innervates the diaphragm, the muscle primarily responsible for inspiration of air into the lungs.
- The 12 paired cranial nerves connect the muscles and structures of the head, face, and neck to the CNS and function as sensory, motor, or both sensory and motor nerves. Important cranial nerves for speech include the trigeminal (V), facial (VII), glossopharyngeal (IX), vagus (X), accessory (XI), and hypoglossal (XII).
- The trigeminal (V) nerve is a paired sensory-motor nerve that transmits sensory information from the upper and lower face to the CNS and transmits motor information from the CNS to the muscles of the mandible. The trigeminal is divided into ophthalmic, maxillary, and mandibular branches.
- The facial (VII) nerve is a paired sensory-motor nerve that provides motor to the face and sensation (taste) from the anterior two-thirds of the tongue and is divided into the temporal and

zygomatic branches, which are bilaterally innervated, and the buccal and mandibular branches, which are unilaterally innervated.
- The glossopharyngeal (IX) nerve is a paired sensory-motor nerve that provides sensory information to the posterior one-third of the tongue and motor information to the pharynx for swallowing.
- The vagus (X) nerve is a paired sensory-motor nerve that provides motor information to the soft palate, pharynx, and larynx and sensory information from the pharynx, larynx, and viscera through its many branches, including the pharyngeal plexus, superior laryngeal nerve (intrinsic and extrinsic branches), and recurrent laryngeal nerve.
- The accessory (XI) nerve is a paired motor-only nerve whose cranial portion works alongside the vagus for innervation of the larynx, pharynx, and velum and whose spinal portion innervates some of the muscles of the shoulders.
- The hypoglossal (XII) nerve is a paired motor nerve that innervates the intrinsic and extrinsic muscles of the tongue.

Review Questions

1. Describe the two major sections of the nervous system, including each section's anatomy and functions.
2. What three gross structures constitute the brain?
3. What are the ridges and valleys of the cerebral cortex called and why are they there?
4. What is myelin? What is the function of myelin and what type of neurons have myelin?
5. Which fissure separates the left and right cerebral hemispheres? What major band of commissural fibers connects the right and left cerebral hemispheres?
6. List five functions of the right hemisphere.
7. List two functions of the left hemisphere.
8. Name the four lobes of the cerebral hemispheres and describe the function and any important areas of each lobe that enable those functions to occur.
9. Which sulci run laterally and divide the frontal and temporal lobes? Which sulci run superiorly to inferiorly and divide the frontal and parietal lobes?
10. List three structures of the subcortex and identify the main functions of those structures.
11. List the three sections of the brain stem and describe functions of each.
12. What structures of the cerebellum attach it to the pons and the CNS?
13. What is the location and primary function of the thalamus?
14. Describe the function of the basal ganglia.
15. Why is the circle of Willis an important structure?
16. Describe the location, anatomy, and role of the spinal cord.
17. Describe how a healthy stretch reflex occurs and describe how a hyperactive stretch reflex contributes to spasticity.
18. In your opinion, which cranial nerve is the most important for speech production and why?
19. What are the six most important cranial nerves that are central to the production of speech?
20. What is bilateral innervation? What is unilateral innervation? Why is bilateral innervation a good thing?

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