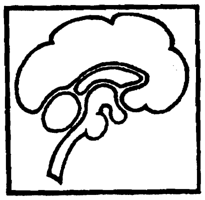

Anatomy 3

How the Brain Controls the Body

Assembling a Person

It is sometime in the future. The young couple are looking forward to the arrival of their first son. He is not going to be an ordinary son, since the mother is not pregnant and the father is not the father. Rarely is anyone born in the usual sense these days. Instead, everyone is recycled.

The couple look through the person catalogue that lists thousands of bodies and brain pieces. They try to be diligent in selecting pieces that will result in the best combination of looks, intelligence, and personality. Of course, once all the pieces are connected, no one knows for certain exactly which traits the new person will have. Try to imagine what an individual would be like if pieces of brain were combined from a hockey player, a poet, and a banker. Yet everyone, including this couple, thinks they know how to combine different parts from different brains to create the best personality.

After they select the body and thousands of brain pieces from the catalogue, the couple will have the exacting task of assembling them. If any of the pieces or nerves are damaged or misconnected, the new person might be abnormal. There have been cases of misassembled individuals who thought that up was down, who could not understand what they said, who could read but not write, and who could see with their fingers. Needless to say, these persons had to be disassembled and begun again.

As the couple picks out the various pieces of brain, they wonder how one puts a human nervous system together. How many pieces of brain must be connected before an individual can breathe, walk, speak, or think? This couple selects the body of a young adult male and thousands of brain pieces that they hope will result in a bright, humorous, and warm personality. In four weeks, the body and brain pieces will arrive and assembly will begin.

The Nervous System

Spinal Cord

The body and brain pieces come packed in a sealed liquid nitrogen container. After breaking the seal, the couple remove the body and place it on a sterile sheet. Next they cautiously remove the thousands of nerves and brain pieces and arrange them in order of assembly.

Impatient to see his son the father does not read the instructions and begins by inserting a brain piece called the *pons*. He waits for the body to react, but nothing happens. The instructions read, "The spinal cord must be inserted before the body can execute any movements." Grudgingly, the father inserts the **spinal cord** into a tubelike structure comprised of a series of connected bones called **vertebrae**. The cord looks like a long, white, smooth rope that reaches from the body's neck to the small of the back. With the spinal cord in place, the father waits for something to happen. The body does nothing.

Spinal Nerves

The instructions continue, "After spinal cord is inserted, connect spinal cord to **spinal nerves**." The spinal nerves had been preconnected to the various muscles and organs of the body, so it remained only for the couple to attach them to the spinal cord. There are thirty-one pairs of spinal nerves, with one nerve of each pair connected to the right side of the spinal cord and the other in each pair to the left side. Depending on their location, spinal nerves have different names. Spinal nerves in the neck area are called **cervical** (SIR-vee-cul); those in the upper back area, **thoracic** (thor-ASS-ic); those in the lower back area, **lumbar** (LUM-bar); and those at the very bottom of the back, **sacral** (SAY-crull).

The mother carefully places each of the spinal nerves near the appropriate area of the spinal cord. The instructions read, "Danger: it is very easy to commit an error at this step. Each spinal nerve is composed of two kinds of cells called neurons. Sensory or afferent neurons, attached to sensors in the skin, muscles, and joints, carry information into the spinal cord. Motor neurons, attached to muscles, carry information out of the spinal cord. Afferent and motor neurons must be attached at different points on the spinal cord."

The mother notices that a spinal nerve looks like a piece of white string that has been split in two parts just before it reaches the spinal cord. The afferent part has a lump, called a *ganglion*, that is a cluster of cell bodies; the motor part of the spinal nerve has no lump. The afferent neurons are attached to the back of the spinal cord in a branch called the **dorsal root**. The motor neurons are attached to the front or stomach side in a branch called the **ventral root**. Hours later, the couple has all 31 pairs of spinal nerves in place.

Reflex

With the spinal nerves attached to the spinal cord, the father tells the body to walk. Nothing. He reads on, "To make sure the spinal cord is functioning, complete the following test. Stick a pin into the thumb. The hand should withdraw." He sticks a pin into the thumb and the hand withdraws. The hand withdrawal is an example of a **reflex**. Reflex behavior is automatic, requires no thinking, and occurs in response to certain kinds of stimuli.

Next he taps below the knee cap and the leg jerks. Another reflex: quick, automatic, no thinking involved. When the knee is tapped, sensors in the knee send this information through afferent neurons in the spinal nerve, through the dorsal root, and into the spinal cord. Once in the spinal cord, the afferent neuron connects with a motor neuron. The motor neuron carries the message through the ventral root and the spinal nerve to the muscles that make the knee jerk. Different parts of the spinal cord control different reflexes: knee jerk is controlled by the lower spinal cord, while hand withdrawal is controlled by the upper spinal cord. Without any control from the brain, the knee is able to jerk and the hand to withdraw. No matter how much the father shouts "walk," a body with just a spinal cord cannot walk, but it can have reflexes. Reflexes are important in protecting your body from many harmful stimuli: removing your hand from a hot stove or blinking your eye at dust or lifting your foot from a sharp stone. These are simple reflexes and do not require any control by the brain. More complex reflexes, such as breathing, require some control by the brain. In addition to controlling some of our reflexes, the spinal cord also carries information to and from the brain, but this function will have to wait until the brain is assembled.

Medulla

Checking the diagram, the father finds the first brain piece that fits on top of the spinal cord, the medulla. It is bigger around than the spinal cord and approximately 8 cm (3–4 inches) in length. Once the medulla is connected to the spinal cord, dramatic changes occur. With the medulla in place, breathing and heart rate are regulated, blood pressure in partly regulated, and intestines may start to contract. The medulla controls many of the more complex reflexes that are vital to staying alive. There is wisdom in the old saying, "Without a medulla you are as good as dead."

Pons

With the spinal cord and medulla in place, the body is capable of many different reflexes, but still no voluntary movements. Back to the instructions. "To the top of the medulla, attach the structure that is approximately 5 cm (2 inches) long, bigger around than the medulla, and called the **pons**." With the pons in place, the body still does nothing. The pons is involved in the regulation of sleep, but unless more of the brain is assembled it is difficult to tell if the body is asleep or awake. As the brain is assembled, many other brain structures will be connected to the pons. Without the pons, the new son would have trouble getting a good night's sleep and would be missing important connections to the rest of his brain.

Reticular Formation

The father and mother name the body "Jack." With each new brain piece added, the father checks to see if Jack will respond to his name or a command, but Jack does not move. Actually, the brain part that allows Jack to wake up is already in place. About as big around as your middle finger, it is a structure that lies in the center of the medulla and pons and is called the **reticular formation** (rah-TICK-you-ler). When more brain is assembled, the reticular formation will help wake Jack up.

When your alarm goes off in the morning, the reticular formation alerts other parts of the brain. Here's how you wake up. As the information from the senses (sound of alarm) is transmitted to the brain, some of this information branches off and goes to the reticular formation. After receiving this information, the reticular formation excites or alerts a certain part of the brain that some message is coming. Once alerted, the brain is ready to process the sensory information. The reticular formation arouses that part of the brain that will be assembled last, the outside layer of the brain called the *cortex*.

If Jack's reticular formation were severely damaged, his cortex could not be aroused and could not process sensory information. If he had no reticular formation, we could not wake him up. He would be in a coma.

The reticular formation has two parts. The part that alerts and arouses the brain and helps to keep Jack in an awake state is called the **reticular activating system** or **RAS**. The other part is involved with muscle movement. With just the spinal cord assembled, it was possible to tap Jack's knee and get a knee-jerk reflex. With the addition of the reticular formation, the movement of the knee jerk can be made larger or smaller. The reticular formation does not cause muscle movements, but it does influence how much tension the muscle has. Whether the muscle is tense or relaxed influences how much the muscle will move. The part of the reticular formation involved in regulation of muscle tension is called the **descending reticular formation** . This area does not initiate movement but rather modifies the movement once it has begun.

Cerebellum

With the pieces of the brain assembled so far—medulla, pons, and reticular formation—Jack is capable of showing only reflexive movements. When his knee is tapped, the

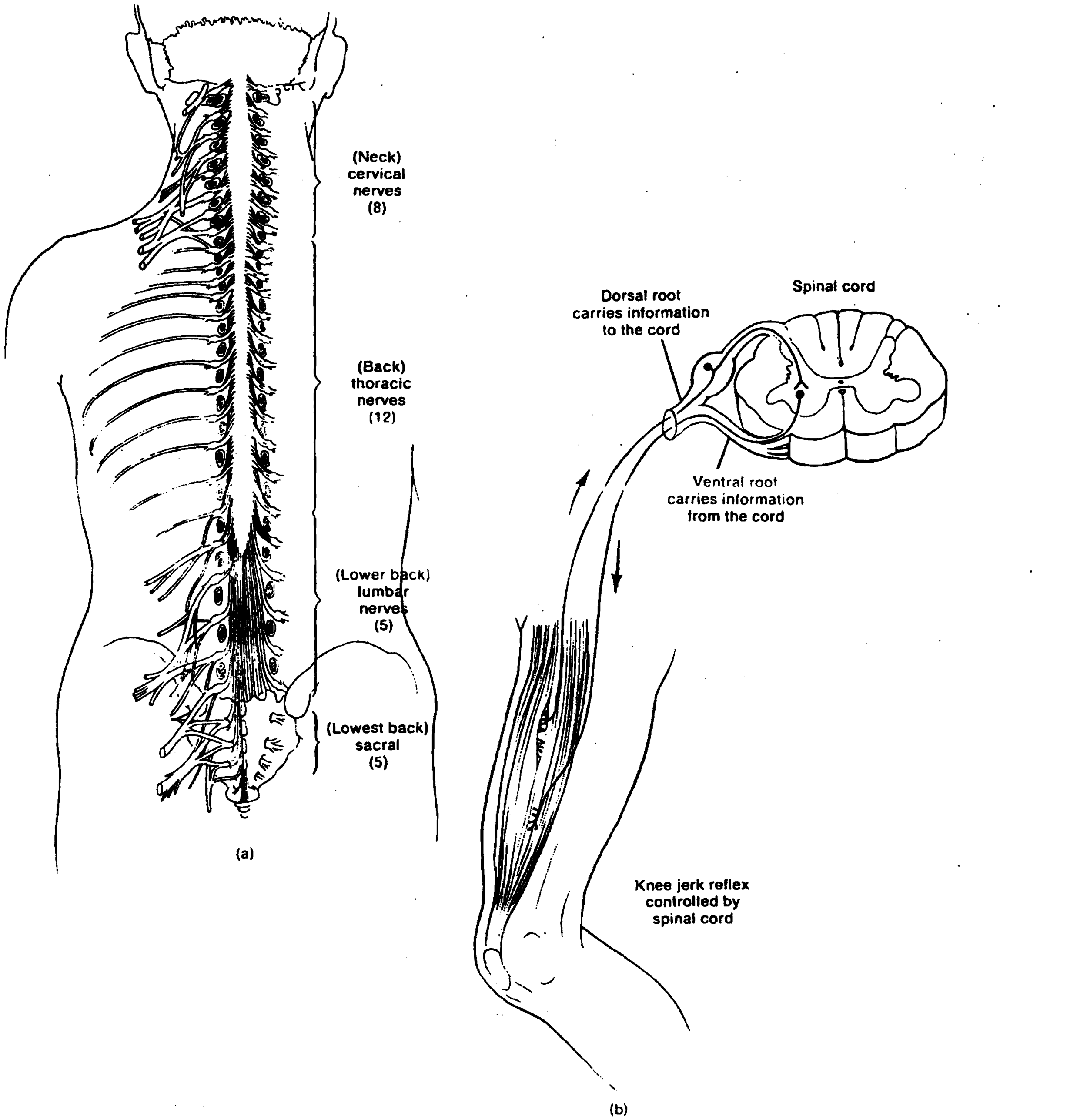

Figure 3-1 How information is carried back and forth to the spinal cord. (a) The spinal nerves receive information from different parts of the body and also send information back to the muscles and glands. (b) An enlargement of one spinal nerve shows that it branches into a dorsal root, which carries information into the spinal cord, and a ventral root, which carries information out to the body.

movement is very sluggish. At first, the couple thinks something is wrong with Jack's spinal cord, since it controls this reflex. But the instructions read, "Muscles will be very weak or lack muscle tone until the **cerebellum** is attached." The cerebellum, about the size of a baseball, is attached right in back of the pons and has many connections with the pons. With the cerebellum in place, Jack's hand withdrawal is a smooth, coordinated movement. The cerebellum provides the muscle tone that is necessary for smooth, coordinated reflexes and for voluntary movements—which Jack cannot yet make. The cerebellum will also help Jack maintain his balance by making adjustments in posture. Without a cerebullum, Jack would have jerky movements and a very uncoordinated walk similar to a drunkard's. If he were to reach for a glass of water without benefit of cerebellum, his hand would shoot past the glass or crash into it, knocking it over. Certain disorders of the cerebellum do cause a drunkard's walk or lack of hand control in reaching for an object.

Hindbrain

The parents are completely baffled by reference to something called the **hindbrain**. They cannot remember assembling it. The instructions read, "Hindbrain check: the hindbrain consists of the medulla, which controls vital reflexes; the pons, which is involved in sleep and makes connections with other parts of the brain, especially the cerebellum; and the cerebellum, which is involved in the coordination of movements." The couple know that the medulla and pons also contain the reticular formation, which is involved in alerting the brain, in maintaining wakefulness, and in controlling muscle tension. The father is pleased that he has single-handedly assembled the hindbrain. Jack is neither pleased nor displeased. Much more brain needs to be assembled before Jack even knows he has a hindbrain.

Midbrain

The instructions read, "It is important to assemble the brain piece by piece. Careless assemblage may lead to the creation of a monster. The next piece of brain, the **midbrain,** is connected to the top of the pons." The mother attaches the midbrain to the top of the pons. There are a series of tests to determine if the midbrain is working. "Stand out of sight and drop a large book on the floor. The head should turn reflexively toward the loud noise. Again, stand out of sight. Take the same large book and throw it close to, but do not hit, the head. The eyes should reflexively detect and blink as the book goes hurling by. Repeat, do not hit the head with the book." The father drops the book and nothing happens. He jumps on top of the book and makes a tremendous racket. Nothing. He reads on, "If the test is a failure, you have omitted a step. Go back and complete the previous step."

Cranial Nerves

Before Jack can turn his head toward a loud noise or blink his eyes or stick out his tongue or smile or taste food, 12 different nerves must be assembled. Ten of these 12 nerves, called **cranial nerves**, are attached at various places along the medulla, pons, and midbrain; two cranial nerves are connected to pieces of the brain not yet assembled. At their other end, the cranial nerves are connected to various sensors, glands, and muscles in the face, head, and neck; and also to the heart and visceral organs, such as intestines. The cranial nerves and their major functions are listed in Table 3–1. It is your cranial nerves that allow you to make faces at the idea of memorizing the names of these 12 nerves.

With the cranial nerves in place, Jack's midbrain functions correctly. The area in the midbrain involved in the reflex of turning toward a noise is called the **inferior colliculus** (ko-LICK-u-lus). The area involved in the reflex of detecting moving objects and blinking is called the superior colliculus.

If the mother had damaged the midbrain in assembly, Jack might not have the above reflexes. Jack might also have muscle weakness, a shuffling walk, a very inexpressive face, and shakes or tremors. Together, these symptoms are called **Parkinson's disease** and can be caused by damage to the midbrain.

The midbrain also contains the top part of the reticular formation that stretches across the medulla and pons into the midbrain. Together the medulla, pons, and midbrain are called the **brainstem**. It would be most correct to say that the reticular formation is located in the brainstem, meaning the medulla, pons, and midbrain. Although Jack now has a large part of the central nervous system assembled—spinal nerves, spinal cord, medulla, pons, cerebellum, midbrain, and cranial nerves—the only responses he can make are reflexes.

Forebrain

The instructions read, "If you have completed the brainstem, you are now ready to assemble the forebrain." All of the structures that will be added above the midbrain are part of the **forebrain**. You will remember from Chapter 1 that the forebrain is the most forward part of the brain and is greatly expanded in humans. The forebrain actually consists of two large **hemispheres** (meaning "half-spheres") and is symmetrical in the same way that your body is symmetrical. In other words, each brain structure found in the left hemisphere is also found in the right. For example, the first forebrain area we will be adding is the hypothalamus (hype-po-THAL-mus). There is actually a hypothalamus in the left hemisphere and one in the right hemisphere, but these are usually referred to in the singular. Thus, you would discuss the hypothalamus, but it would be understood that you meant the hypothalamus in both hemispheres.

Hypothalamus

The instructions read, "This structure is critical to a well-functioning body. Attach the **hypothalamus** above and in front of the midbrain." Jack needs a hypothalamus to regulate his eating, drinking, temperature, secretion of hormones, emotional responses, and possibly sexual behavior. Not only is the hypothalamus involved in all of these func-

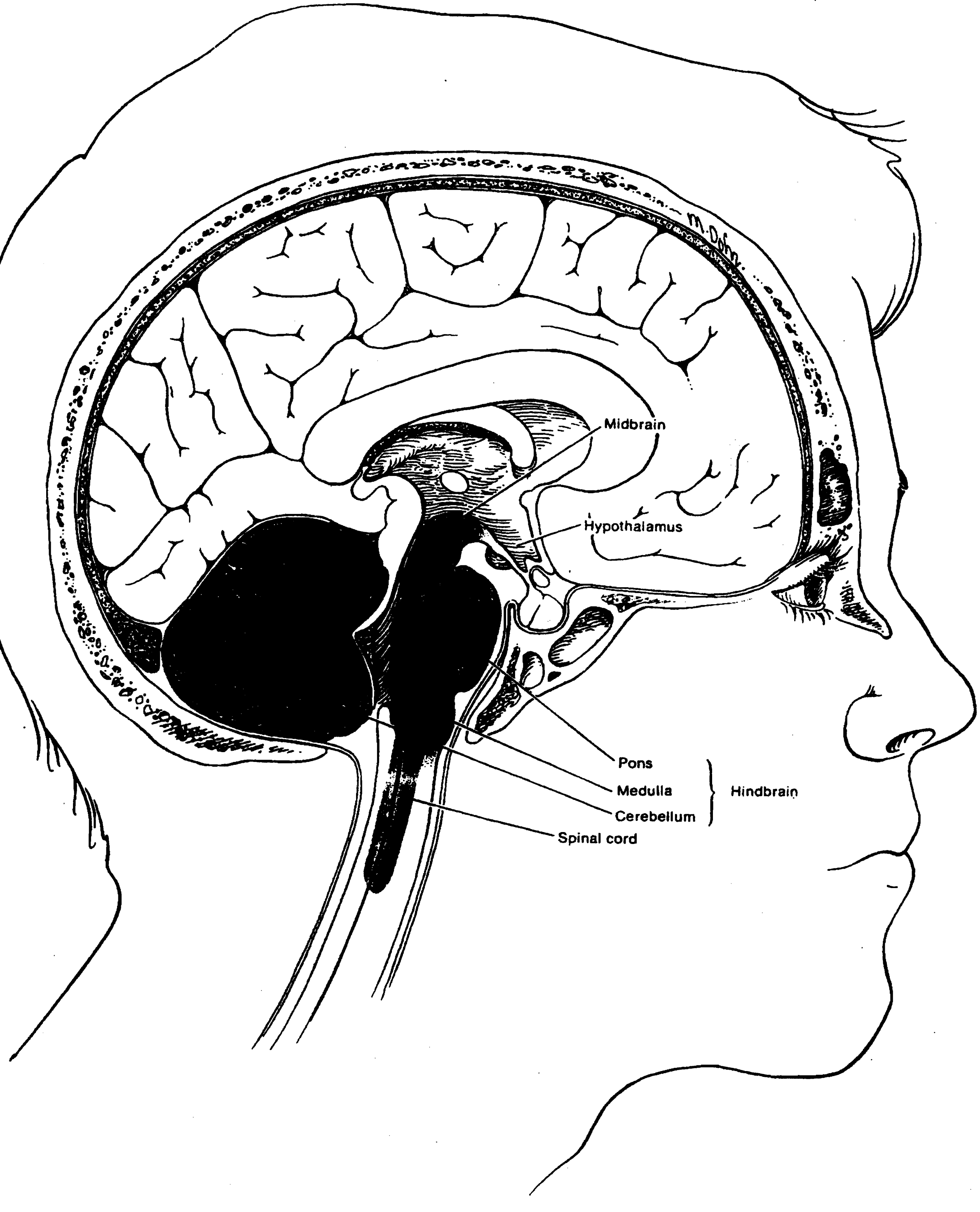

Figure 3–2 A middle view of the brain showing the location of the hindbrain, including medulla, pons, and cerebellum; the midbrain; and the hypothalamus. The reticular formation lies in the medulla and pons, extending slightly into the midbrain.

TABLE 3–1 The Cranial Nerves

Designated by Number	*Name*	*Functions*	*Point Where Nerve Begins or Ends in Brain*
I	Olfactory	Smell	Under front part of brain
II	Optic	Vision	Thalamus
III	Oculomotor	Eye movement	Midbrain
IV	Trochlear	Eye movement	Midbrain
V	Trigeminal	Eating movements and sensations from face	Midbrain and pons
VI	Abducens	Eye movement	Medulla
VII	Facial	Face movements and taste	Medulla
VIII	Auditory	Hearing and balance	Medulla
IX	Glossopharyngeal	Taste and pharynx movements	Medulla
X	Vagus	Heart, blood vessels, and viscera	Medulla
XI	Spinal accessory	Neck muscles and viscera	Medulla
XII	Hypoglossal	Tongue muscles	Medulla

These are the 12 cranial nerves; they are referred to either by name or by number. Some of these nerves carry sensory information, some carry motor information, and still others carry both sensory and motor information.

tions, but it is connected to many other brain areas with even more functions. Without a hypothalamus, Jack would starve, not drink, be unable to retain water, be generally miserable, and die.

Thalamus

The next instruction reads, "Right above the hypothalamus, insert a structure about the size of a walnut, the **thalamus** (THAL-mus). If you damage the thalamus in assembly, the body will be blind, deaf, and unable to feel any sensations when touched." But even with the thalamus in place, Jack still cannot see or hear. For Jack to hear, understand, and respond to his name, he will need both the thalamus and the piece of brain that comes last, the cortex. The thalamus is involved in the relay of information coming from the senses to the cortex. Sensors in the body send information into the spinal nerves and up to the spinal cord. Sensors in the face and head send information into the cranial nerves. Much of the sensory information carried by the spinal cord and cranial nerves goes to the thalamus. The thalamus has been called a great relay center because it relays the sensory information about vision goes to the **lateral geniculate** (jen-ICK-you-lit) nuclei, and information about hearing goes ral of *nucleus*. A nucleus is a group of cell bodies of neurons that are gathered together in one place in the central nervous system.)

Sensory information about touch, temperature, and pain goes to the **ventrobasal** (ven-tro-BASE-all) nuclei of the thalamus. If Jack's ventrobasal nuclei were damaged, he would not know if he were being touched because this information could not be transmitted to the cortex. Sensory information about vision goes to the **lateral geniculate** (jen-ICK-you-lit) nuclei, and information about hearing goes to the **medial geniculate** nuclei. If the lateral and medial geniculate nuclei were damaged, Jack would be just as blind and deaf as if his eyes and ears had been destroyed.

In addition to the above nuclei, the thalamus has many others. Some are involved in sleep and waking and others gather information from many different areas and send it to the cortex. The thalamus is called the relay station because most of the sensory information that goes to the cortex must pass through the thalamus; however the thalamus is more that a relay station. The thalamus changes or modulates sensory information and also integrates information from many different brain areas. With his thalamus in place, Jack still cannot hear his name but he has one of the structures necessary for hearing.

Basal Ganglia

The father is confident that the next brain structure will get Jack moving. The label reads, "Brain part #14, **basal ganglia**, part of motor system." The instructions state, "Place the next three parts above and to the side of the thalamus. All three parts must be assembled together, or severe problems in movement will develop." Slightly larger than the thalamus, these three areas together are the basal ganglia. If Jack is ever to play tennis, he must have his basal ganglia. Earlier it was said that Parkinson's disease was caused by damage to an area of the midbrain. More often, in Parkinson's disease there is damage to both the midbrain and the basal ganglia.

If Jack develops Parkinson's disease his muscles will become increasingly stiff and he will have tremors and difficulty in starting movements. For example, he will have trouble starting a swing with his racket and, once he has started, he will have trouble stopping. Both the midbrain and

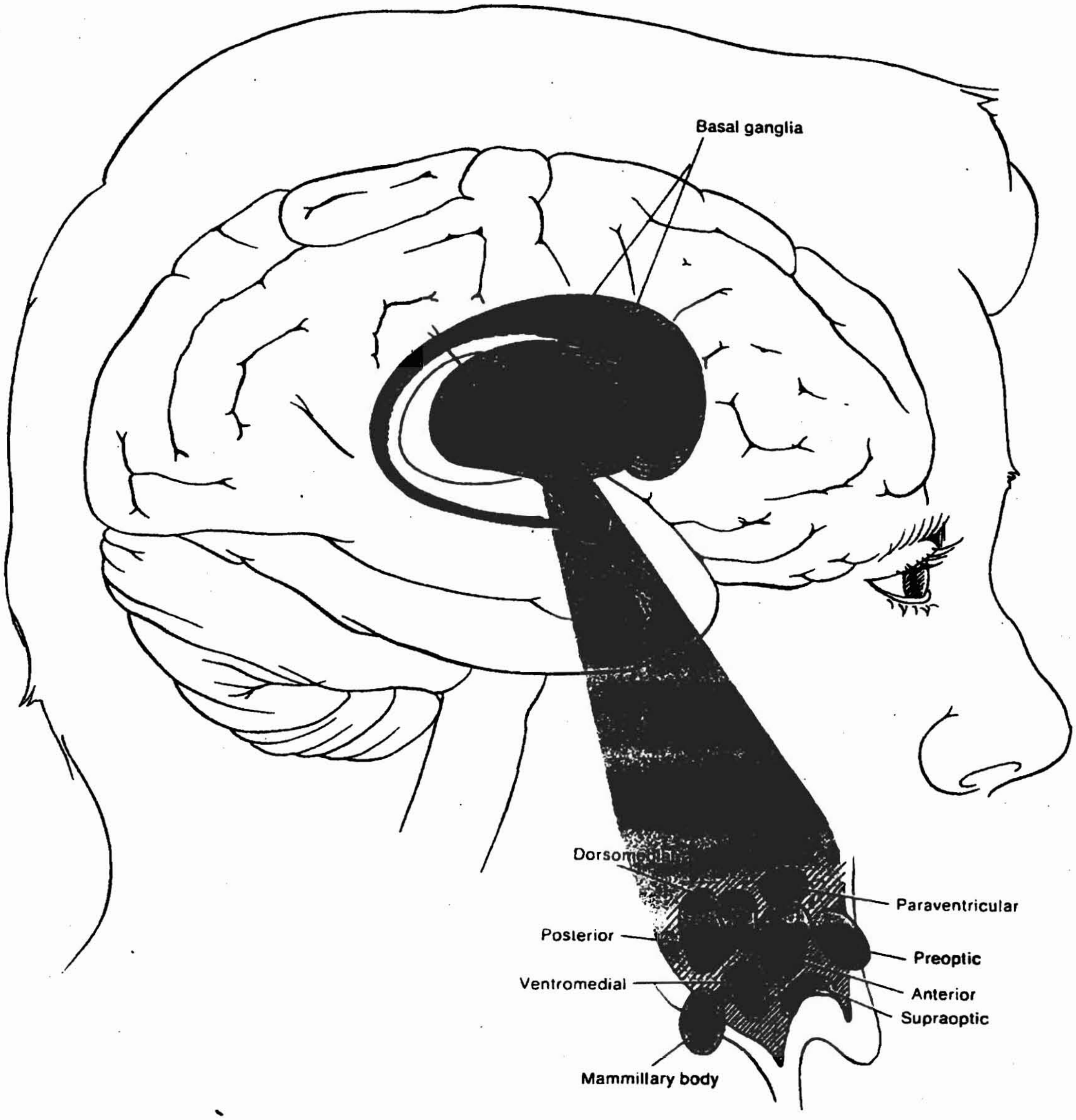

Figure 3–3 The location of the basal ganglia, above and to the side of the hypothalamus. The enlargement of the hypothalamus shows its many separate nuclei.

the basal ganglia are involved in the control of muscles for walking, swinging the arms, and starting and stopping.

These areas, midbrain and basal ganglia, together with the cerebellum, make up the **extrapyramidal motor system** (extra-per-RAM-id-all). The extrapyramidal system, alone, does not make voluntary movement possible, but it is very important for the regulation of muscle tone and movements. If your extrapyramidal motor system is damaged, you should consider selling your tennis racket.

Hippocampus and Amygdala

Jack would need only one novel for the rest of his life if he had no **hippocampus.** He could read the same story over and over, thinking he was reading it for the first time. The hippocampus is involved in memory. It is approximately the size of the bent hotdog and is located below and to the side of the basal ganglia.

A structure that looks like an olive is placed right in front of the hippocampus; it has an equally strange name. This is the **amygdala** (a-MIG-da-la) and it is involved in emotional behavior. If Jack had no amygdala, he might show very little emotion or enthusiasm. He would not care whether he won or lost at tennis and he would never get mad at a bad shot. The amygdala and hippocampus are connected to many other brain structures and, because of these connections, are involved in other behaviors.

Cortex

Only two pieces of brain remain to be assembled. Either Jack will soon move and respond to his name or the entire brain will have to be reassembled. The mother picks up a structure that is about as thick as a piece of cardboard and very wrinkled, and places it on top of all other structures in the forebrain. This is the **cortex**. If you wanted to put a large piece of paper in a very small box, you might wrinkle up the paper. That is essentially what happened to the cortex. The skull, like a small box, did not provide enough space; by evolving in a wrinkled fashion, the cortex was able to have more area that if it were smooth. The top of a wrinkle is called a **gyrus** (JI-russ) and the bottom of a wrinkle is called a **fissure** or **sulcus** (SUL-kus). (Use your hippocampus to remember that).

Jack is capable of acting like a human because of the cortex. It contains approximately 10 billion neurons that allow you to think, dream, reason, talk, walk, see, hear, and learn. Beginning with the day you were born, and even in the womb, you were constantly experiencing, integrating, and responding to the world around you. The cortex is involved to a large extent in processing these millions of experiences and learning or not learning from them. In the year 2880, these millions of experiences are programmed into Jack's cortex by computer.

The cortex has a number of curious features. For example, the *left* side of the cortex receives information from the right side of the body and controls the movements of the right side. The *right* side of the cortex receives information from the left side of the body and controls movements on the left side. Exactly how this arrangement came about probably is to be found in your evolutionary past.

Auditory Area

The father begins assembling the cortex. When it is assembled, the wrinkled cortex will look the same throughout. However, different areas of the cortex have different functions. The instructions say there are four lobes and that the first one to look for is the **temporal lobe**. He finds this lobe and discovers that it actually has two parts that are positioned at either side of the brain.

At the moment when the father places the right temporal cortex alongside and near the bottom of the forebrain, Jack can hear. The medial geniculate nucleus of the thalamus relays information from the ears to this area in the temporal lobe. The boundary of the temporal lobe is a fissure running laterally up the brain and called the **lateral fissure**.

When Jack's left temporal cortex is in place, he will also have the part of the brain needed for speaking. For most people, speech is controlled in the left temporal lobe, but much more that that is needed for speech.

Motor Area

Another piece of cortex is placed over the front part of the brain. At this moment, Jack can reach for his tennis racket. He now has a **frontal lobe**, which, among other functions, controls voluntary movements. The system that controls voluntary movements is called the **pyramidal system**. It is named for the pyramidal shape of the neurons in the motor area. When Jack reaches for his tennis racket, messages to move his arm start in the motor area of the frontal lobe and travel down his spinal cord. There, they activate other neurons that travel to the muscles in his arm. At the same time, the extrapyramidal motor system (basal ganglia and cerebellum) are involved in regulating and coordinating the arm's movements. But, without the portion of the frontal lobe called the **motor area**, Jack could not make any voluntary movements. The rear boundary of the frontal lobe is the **central sulcus**, which runs down the side of the brain. The motor area is immediately in front of the central sulcus.

When Jack picks up the racket with his right hand, it is the motor area in the cortex of the left hemisphere that controls the movement. If there were damage to Jack's motor area on the right side, the left side of his body would be paralyzed. As the neurons leave the right motor area, they travel through other areas of the brain, cross over to the left side in the brainstem, and travel down the left side of the spinal cord to control the left side of the body. If only a tiny spot in the motor area were damaged, only an arm might be paralyzed, and the other parts of the body spared. This is because all of the different areas of the body are represented at different locations in the motor area. As you see in Figure 3–5, the control of mouth movements is on the side of the motor area, while the control of knee movements is on the very top.

A curious feature of the motor area is that it has a large area for mouth and face movements and a very small area for chest movements. The rule is: the more complex the movement, the larger the area on the motor cortex. A large area of the motor cortex is devoted to finger movements, because it requires millions of neurons to control all the complex movements the fingers can make. A smaller area of the motor cortex is devoted to back movements, because it requires fewer neurons to control the general movements of the back.

Somatosensory Area

Jack can hear and can reach for the tennis racket, but he cannot yet feel the racket. Behind the frontal lobe and therefore behind the central sulcus, goes a piece of cortex forming the **parietal lobe** (pear-ee-EYE-tall). An area in the parietal lobe called the **somatosensory area** enables Jack to experience touch and temperature. Jack can feel that the racket handle is smooth and cold because of this **somesthetic cortex**. The ventrobasal nucleus of the thalamus relays information from the sensors in the body to the somesthetic area in the parietal lobe. If Jack grabs the racket with his right hand, the sensory information goes to the left somesthetic cortex. As in the motor area, different parts of the body are represented at different locations in the somesthetic area.

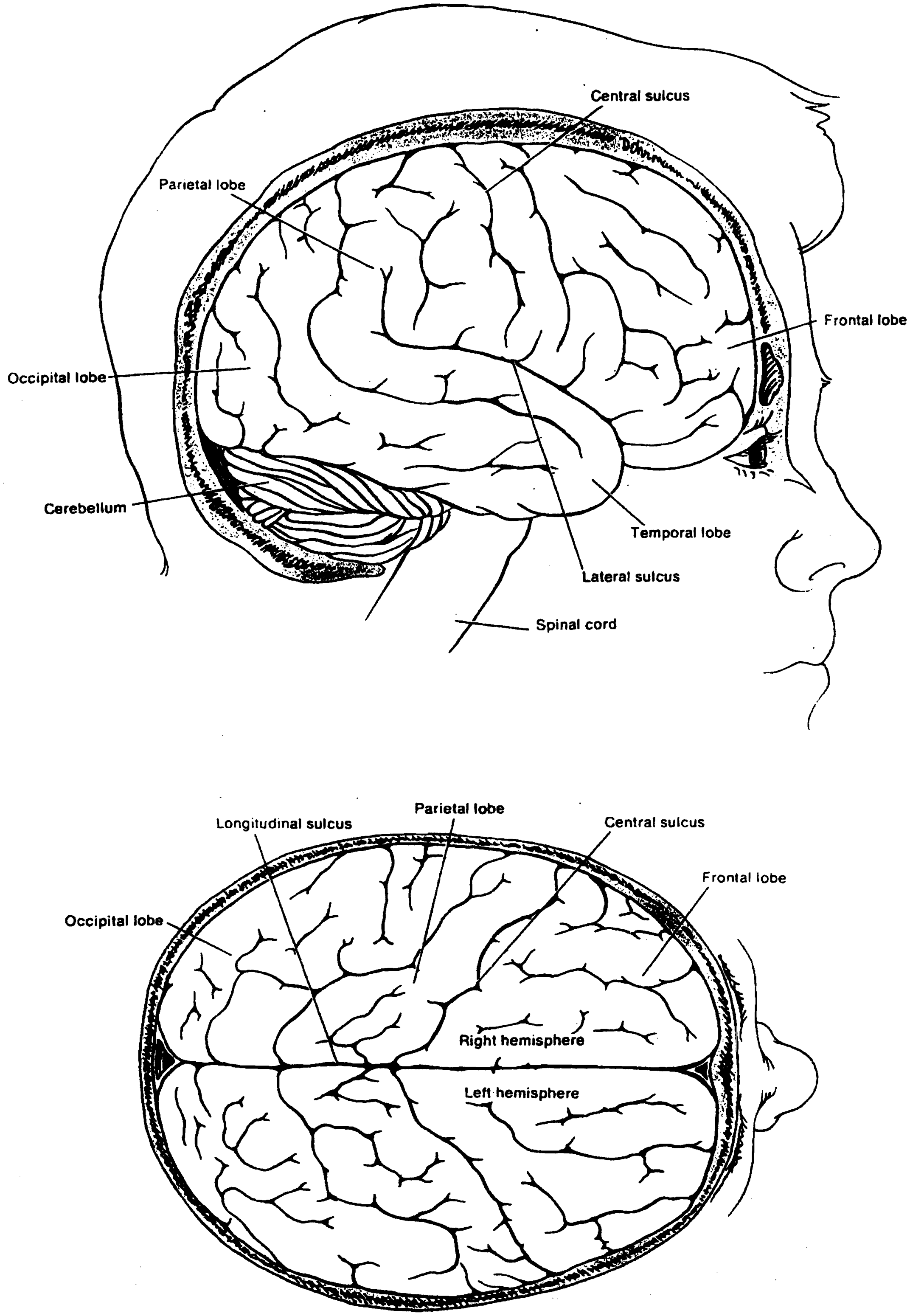

Figure 3–4 The side view of the brain shows the four lobes: frontal, parietal, temporal, and occipital. The top view shows how the brain is divided down the middle by the longitudinal sulcus into a right and left hemisphere. The central sulcus lies between the frontal and parietal lobes, and the lateral sulcus separates the temporal lobe. There is no sulcus defining the occipital lobe.

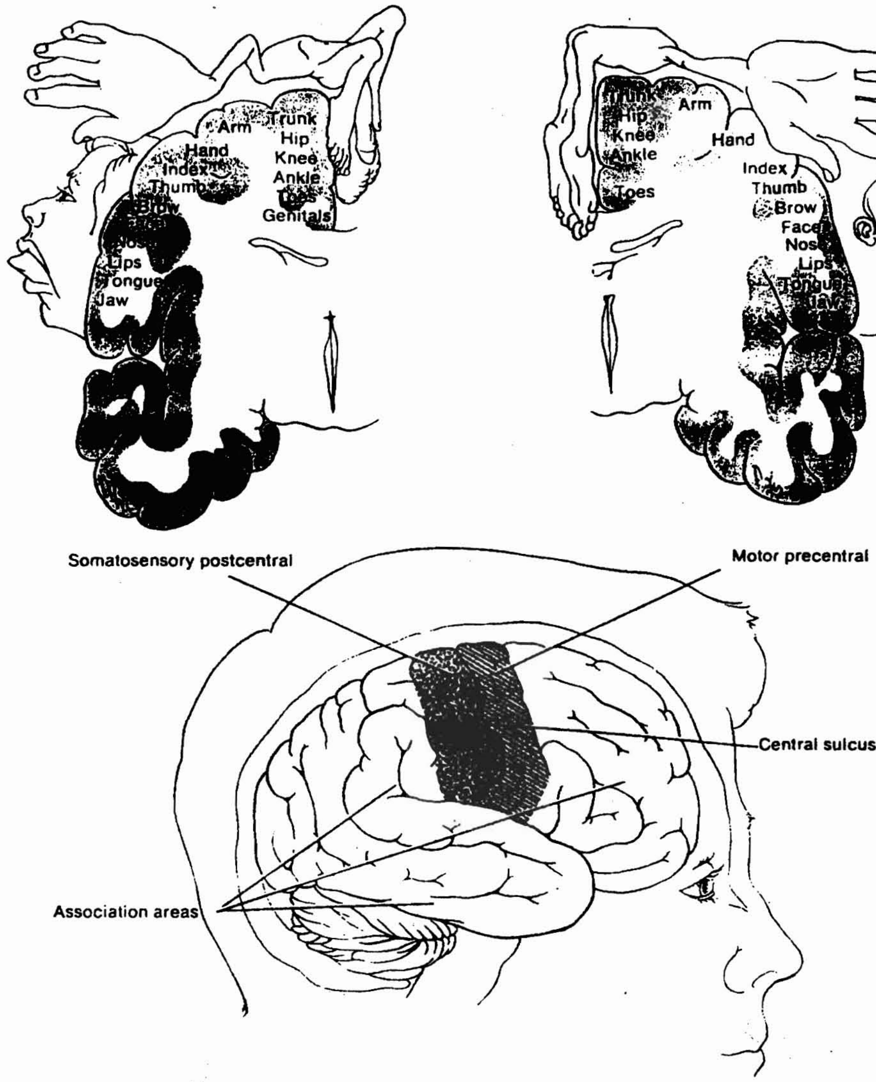

Figure 3–5 This side view of the brain shows how the central sulcus separates the motor area (precentral) in the frontal lobe from the somatosensory area (postcentral) in the parietal lobe. The figures above are schematic representations of cortical functions. Different parts of the body have larger or smaller areas on the motor cortex depending upon the complexity of movement. For example, fingers have greater complexity of movement and therefore have a larger area on the cortex than toes have. Similarly, different parts of the body have larger or smaller areas on the somatosensory cortex depending upon the sensitivity. For example, the tongue is very sensitive and therefore has a larger area than a knee has.

Visual Area

Finally, the mother places the last piece of cortex on the very back of the brain. At that moment, Jack can see. This fourth lobe, called the **occipital lobe** (awk-SIP-ah-tall), is the area involved in vision. The lateral geniculate nucleus of the thalamus relays information from the eyes to an area in the occipital lobe. There is no noticeable sulcus separating the parietal and occipital lobes.

Association Areas

Perhaps Jack is thinking about playing tennis, or is fantasizing about winning, or is figuring out how to serve better. There is no one area of the cortex responsible for these complex responses of thinking, reasoning, and fantasizing. Areas involved in thinking and reasoning and associating are called **association areas**. Association areas are scattered throughout the four lobes and comprise a large part of the cortex.

Cortex Alerted

Only when the cortex was assembled, could Jack hear and understand his name or think about playing tennis. For the cortex to process sensory information from the ears or other senses, the cortex must be alerted or aroused. When the father shouts "Jack," sensory information from the ears enters the brain and does two things. Some of the information goes into the reticular formation, which immediately sends messages to alert the cortex that some information is coming. Additionally, sensory information from the ears goes to the thalamus (medial geniculate nuclei), which relays the information to the cortex in the temporal lobe. With the cortex alerted, these sensory messages are processed and understood.

Corpus Callosum

One last piece must be added to make the brain complete. The brain is separated into a right and left hemisphere by a wide sulcus called the **longitudinal sulcus**. With the brain in two halves, there must be some way for the right hemisphere to know what the left hemisphere is doing. The final instructions read, "To connect the two hemispheres, place a structure called the **corpus callosum** between the two halves." The corpus callosum is about 1 cm (½ inch) thick and is a bundle of nerve fibers that connects the two hemispheres. If Jack did not have a corpus callosum, his left hemisphere would not always know what his right hemisphere was doing, which could be embarrassing. Without a corpus callosum, he might be swinging his racket at the ball with one hand and trying to catch the ball with the other.

A Functioning Body

With Jack's brain assembled and working, it is time for the couple to determine whether his body is functioning normally. There are a number of glands which secrete chemicals necessary for his well being. If one of these glands had malfunctioned, Jack might have been very short like a dwarf, or very tall like a giant, or have diabetes or muscle spasms. Jack's body came with these glands preassembled, so the couple must check to see that they are in working order.

The various glands that secrete hormones operate automatically and are not under conscious control. Glands that secrete their hormones directly into the blood stream are called **endocrine glands**. Once released into the blood stream, the hormones act on target organs or glands in various parts of the body. The level of hormones in the body is regulated through a feedback system. Normally, your hormones are regulated without problem. If this regulation should break down, there can be physiological problems or psychological problems.

Thyroid: Metabolism Control

Jack's body has two **thyroid glands**, one on each side of his neck just below the voice box. The thyroid secretes a hormone called **thyroxin**. If too little thyroxin is secreted when a child is growing and replacement hormones are not administered, the child will be short for his age, have a pot belly and a protruding tongue, and be mentally retarded. A child with this thyroxin deficiency is called a *cretin*. The secretion of thyroxin causes the cells of the body to increase their activity or metabolic rate. An abnormally low metabolic rate would mean slower growth, resulting in an inability to reach full potential, as seen in the cretin.

If you had normal secretion of thyroxin as a child but too little as as adult, you would be sluggish, have reduced muscle tone, and experience lowered motivation and alertness. These symptoms can be cleared up with the administration of thyroxin. If an adult has too much thyroxin, which is less common than too little, the result is nervousness, irritability, and a high metabolism rate. As a result of the higher metabolic rate, this individual eats large amounts of food but does not gain weight. Treatment for too much secretion entails removal of part of the thyroid gland.

Pituitary: Master Gland

In a bony cavity at the base of the brain, hanging directly below the hypothalamus, is the **pituitary** gland. This gland controls many other glands throughout the body. The pituitary is divided into two parts: the **anterior pituitary**, which is controlled by hormones released from the hypothalamus; and the **posterior pituitary**, which is controlled by nerve impulses from the hypothalamus. The hypothalamus, then, controls the pituitary, which in turn controls other glands, such as the thyroid.

It is thought that the hypothalamus releases a hormone called **thyroid releasing factor**, or **T-RF**, that triggers the anterior pituitary to release a thyroid stimulating hormone, **thyrotropin**, or **TSH**. TSH triggers the thyroid gland to produce thyroxin. If secretion of thyroxin were to continue unchecked, the rate of metabolism would be too high and we would see the symptoms of an overactive thyroid. There is a mechanism to turn off secretion of thyroxin. When thyroxin builds up in the blood, it suppressess T-RF from the hypothalamus. Without this releasing factor, the production of thyrotropin stops and the thyroid is no longer stimulated to release thyroxin. Thus, the level of the hormone in the blood effects the hypothalamus, causing it either to start or stop secreting the releasing factor. This interaction between hormone level in the blood and secretion of releasing factors by the hypothalamus is called a **feedback system** and is characteristic of how normal levels of hormones are maintained in the body.

Parathyroid: Calcium Control

Following early attempts to remove thyroid glands from patients with too much thyroxin secretion, it was discovered that these patients sometimes developed uncontrollable