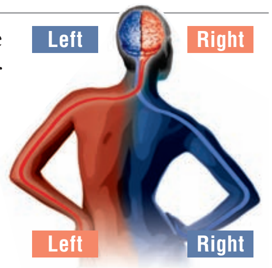
D. Control Centers: Four Lobes

Frontal Lobe: Functions

How do you move your right hand?

The organization of the frontal lobe is somewhat confusing because it has such a wide range of functions, from motor movements to cognitive processes. We'll first focus on motor movements, which have a very unusual feature.



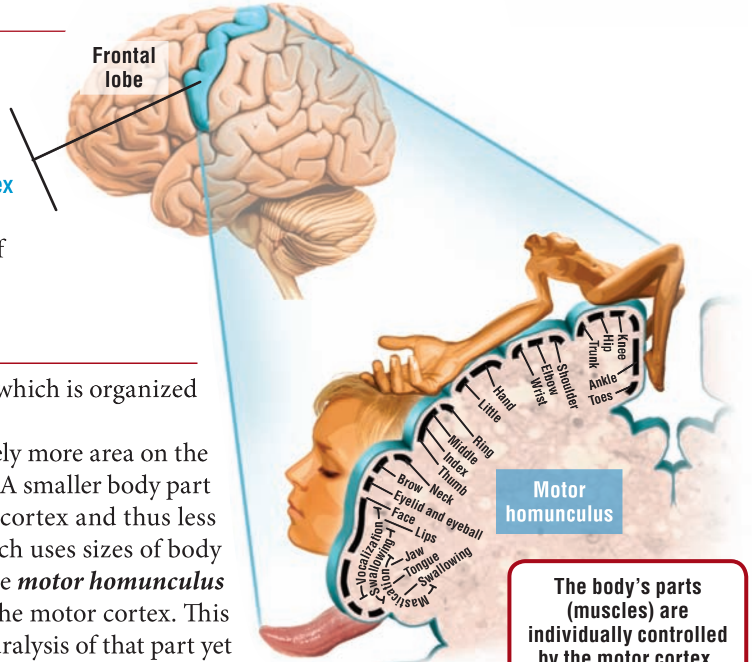
In the figure on the right, notice that nerves from the left hemisphere (blue) cross over and control the movements of the right hand and right side of the body; nerves from the right hemisphere (red) cross over and control the movements of the left hand and left side of the body. The ability to move your hand or any other part of your body depends on the motor cortex in the right and left frontal lobes.

Location of Motor Cortex

To move your right hand, you will use the motor cortex in your left frontal lobe.

The ***motor cortex*** is a narrow strip of cortex that is located on the back edge of the frontal lobe and extends down its side. The motor cortex is involved in the initiation of all voluntary movements. The right motor cortex controls muscles on the left side of the body, and vice versa.

You can move any individual part of your body at will because of how the motor cortex is organized.



The body's parts (muscles) are individually controlled by the motor cortex.

Organization and Function of Motor Cortex

The figure on the right shows an enlarged part of the motor cortex, which is organized in two interesting ways.

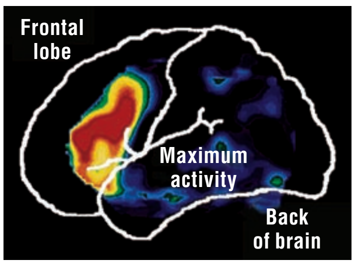
First, a larger body part (notice huge hand area) indicates relatively more area on the motor cortex and thus more ability to perform complex movements. A smaller body part (notice small knee area) indicates relatively less area on the motor cortex and thus less ability to perform complex movements. This unusual drawing, which uses sizes of body parts to show the ability to perform complex movements, is called the ***motor homunculus*** *(ho-MONK-you-luss).* **Second,** each body part has its own area on the motor cortex. This means that damage to one part of the motor cortex could result in paralysis of that part yet spare most other parts. However, recent studies indicate that the motor cortex is not as discretely organized as once believed. Instead of each body part having a different discrete area, there is considerable overlap between body parts in the motor cortex (Purves et al., 2008). Finally, notice that the motor cortex makes up only a relatively small part of the entire frontal lobe.

In a surprising finding, there was vigorous activity in the motor cortex when people did nothing more than silently read action words. For example, when people read the word *lick,* activity occurred in parts of the motor cortex associated with the tongue and mouth (Hauk et al., 2004). This means that besides triggering voluntary movements, the motor cortex responds to simply hearing action words, such as *kick, hit,* or *run.* Next, we'll explain the frontal lobe's other functions.

Other Functions of Frontal Lobe

Executive function. Much of our knowledge of other frontal lobe functions comes from brain scans on both individuals who had damage to that area and healthy individuals. Researchers have found that the frontal lobes are involved in paying attention, organizing, planning, deciding, and carrying out cognitive and social-emotional behaviors, including self-control. Frontal lobes are said to have an **executive function**—that is, act similar to a smart, successful executive of a large organization (B. L. Miller & Cummings, 2007; von Hippel, 2007).

Memory. Brains scans used on individuals without brain damage have led to interesting discoveries about frontal lobe functions. For example, after subjects were shown a series of word pairs, such as *ordeal* and *roach,* they were shown one word from each pair *(ordeal)* and asked to either think about or avoid thinking about the associated word *(roach).* Brain scans, such as the one shown below, indicated that people who best avoided thinking about the associated word had maximum activity in the frontal lobe. This means the frontal lobe is involved in memory, specifically intentional forgetting (M. C. Anderson et al., 2004).



Aging. The frontal lobes shrink as we age, creating impairment in our executive functions, such as inhibiting unwanted speech (a type of self-control). Although older adults understand social rules, they often inappropriately ask others embarrassing questions in public settings and talk at great length about topics irrelevant to a conversation, both of which demonstrate executive function impairments (Begley, 2007b; von Hippel, 2007).

Immediately behind the frontal lobe is the parietal lobe, which, among other things, keeps track of your body's limbs.

Photo Credit: bottom, Courtesy of J.A. Fiez, Dept. of Neurology, Washington University School of Medicine

Parietal Lobe: Functions

How do you know where your feet are?

Every second of every minute of every day, your brain must keep track of what's touching your skin, where your feet and hands are, and whether you're walking or running. All this is automatically and efficiently done by your parietal lobe (right figure).

The ***parietal lobe*** is located directly behind the frontal lobe. The parietal lobe's functions include processing sensory information from body parts, which includes touching, locating positions of limbs, and feeling temperature and pain, and carrying out several cognitive functions, such as attending to and perceiving objects.

For example, the ability to know what you're touching involves the parietal lobe's somatosensory cortex.

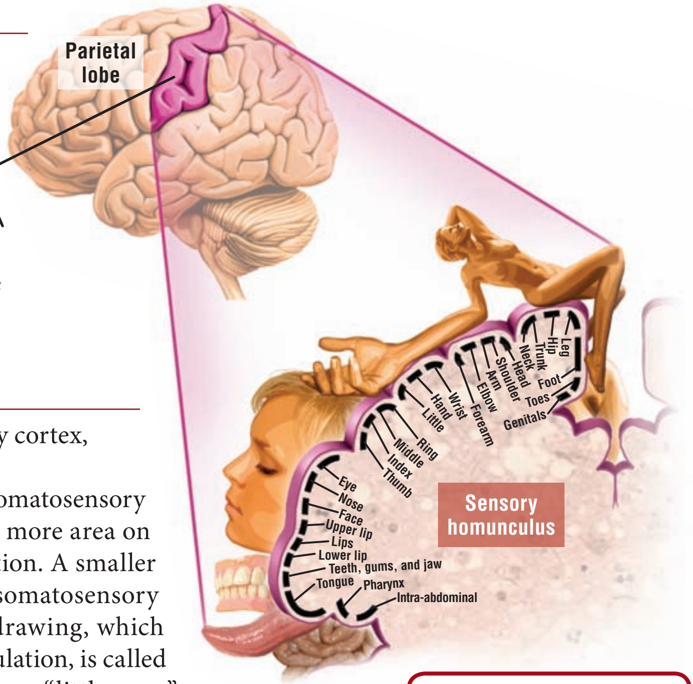
Parietal lobe processes information from body parts.

Location of Somatosensory Cortex

Knowing what you're touching or how hot to make the water for your shower involves the somatosensory cortex.

The ***somatosensory cortex*** is a narrow strip of cortex that is located on the front edge of the parietal lobe and extends down its side. The somatosensory cortex processes sensory information about touch, location of limbs, pain, and temperature. The right somatosensory cortex receives information from the left side of the body, and vice versa.

Your lips are much more sensitive than your elbows because of the way the somatosensory cortex is organized.



Information from body parts (skin, muscles, etc.) is individually processed by the somatosensory cortex.

Organization of Somatosensory Cortex

The large figure on the right shows an enlarged part of the somatosensory cortex, which is also cleverly organized.

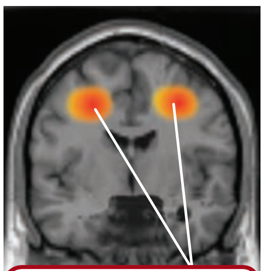
First, notice the different sizes of the body parts drawn on top of the somatosensory cortex. A larger body part (notice large area for lips) indicates relatively more area on the somatosensory cortex and thus more sensitivity to external stimulation. A smaller body part (notice small nose area) indicates relatively less area on the somatosensory cortex and thus less sensitivity to external stimulation. This unusual drawing, which uses sizes of body parts to indicate amount of sensitivity to external stimulation, is called the ***sensory homunculus*** *(ho-MONK-you-luss).* In Latin, *homunculus* means "little man." Notice that the somatosensory cortex makes up only a small part of the parietal lobe.

Second, notice that each body part has its own area on the somatosensory cortex. This means that damage to one part of the somatosensory cortex could result in loss of feeling to one part of the body yet spare all others. Next, we'll explain the parietal lobe's other functions.

Other Functions of Parietal Lobe

Sensory integration. When you put your hand in your pocket, you can easily distinguish a key from a stick of chewing gum because your parietal lobe digests information about texture, shape, and size and "tells you" what the object is. However, patients with damage to the back of their parietal lobes cannot recognize common objects by touch or feel (Bear et al., 1996). Evidence that the parietal lobes are involved in other cognitive processes comes from studies using brain scans.

Spatial orientation. The parietal lobe is involved in processing spatial information (P. H. Weiss et al., 2006). For example, when you are judging the location and distance you must throw a football, your parietal lobe is working to enable you to complete a successful throw.



Maximum activity in parietal lobe.

Language abilities. Subjects were asked to participate in a writing exercise while researchers investigated changes in their brain activity. fMRI scans, such as the one shown here, indicated that maximum activity during this task occurred in the parietal lobe (Menon & Desmond, 2001). Another fMRI study on people who fluently speak a second language indicated the parietal lobe was more developed (or larger) than in those who spoke only one language (Mechelli et al., 2004).

Other functions. Research using brain scans shows that the parietal lobes are involved in additional cognitive functions, such as visual and auditory attention, memory, and numerical processing (counting) (Hao et al., 2005; Hubbard et al., 2005; Shomstein & Yantis, 2006; Simons et al., 2008).

Immediately below the parietal lobe is the temporal lobe, which we'll examine next.

D. Control Centers: Four Lobes

Temporal Lobe: Functions

Did you hear your name?

You recognize your name when you hear it spoken; because of the way sound is processed in the temporal lobe, you know it's not just some meaningless noise.

The ***temporal lobe*** is located directly below the parietal lobe and is involved in hearing, speaking coherently, and understanding verbal and written material.

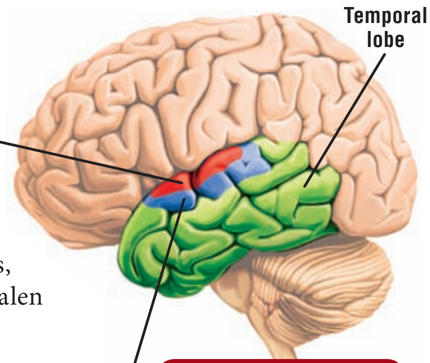
As you'll see, the process of hearing and recognizing your name involves two steps and two different brain areas.

Primary Auditory Cortex

The first step in hearing your name occurs when sounds reach specific areas in the temporal lobe called the primary auditory (hearing) cortex; there is one in each lobe.

The ***primary auditory cortex*** (shown in red), which is located on the top edge of each temporal lobe, receives electrical signals from receptors in the ears and transforms these signals into meaningless sound sensations, such as vowels and consonants.

At this point, you would not be able to recognize your name because the primary auditory cortex only changes electrical signals from the ears into basic sensations, such as individual sounds, clicks, or noises. For these meaningless sound sensations to become recognizable words, they must be sent to another area in the temporal lobe, called the auditory association area (Whalen et al., 2006).



Auditory Association Area

The second step in recognizing your name is when the primary auditory cortex sends its electrical signals to the auditory association area; there is one in each lobe.

The ***auditory association area*** (shown in blue), which is located directly below the primary auditory cortex, transforms basic sensory information, such as noises or sounds, into recognizable auditory information, such as words or music.

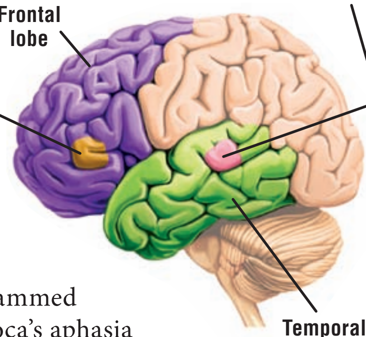
It is only after auditory information is sent by the primary auditory cortex to the auditory association area that you would recognize sounds as your name, or words, or music (D. H. Whalen et al., 2006). So, it is safe to say that you hear with your brain rather than your ears.

Besides being involved in hearing, the temporal lobe has other areas that are critical for speaking and understanding words and sentences.

Broca's Area—Frontal Lobe

Just as hearing your name is a two-step process, so is speaking a sentence. The first step is putting words together, which involves an area in the frontal lobe called Broca's *(BROKE-ahs)* area.

Broca's area, which is usually located in the left frontal lobe, is necessary for combining sounds into words and arranging words into meaningful sentences. Damage to this area results in ***Broca's aphasia*** *(ah-PHASE-zz-ah),* which means a person cannot speak in fluent sentences but can understand written and spoken words.



The reason that saying words and putting words into sentences come naturally to small children is that Broca's area is genetically programmed to do this task. If it is damaged, people with Broca's aphasia have difficulty putting words into sentences. For example, a patient was asked, "What have you been doing in the hospital?" The patient answered, "Yes, sure. Me go, er, uh, P.T. non o'cot, speech . . . two times . . . read . . . wr . . . ripe, er, rike, er, write . . . practice . . . get-ting better" (H. Gardner, 1976, p. 61). The patient was trying to say, "I go to P.T. (physical therapy) at one o'clock to practice speaking, reading, and writing, and I'm getting better."

A patient with Broca's aphasia cannot speak fluently but can still understand words and sentences because of a second area in the temporal lobe—Wernicke's area (Swanberg et al., 2007).

Wernicke's Area—Temporal Lobe

The first step in speaking is using Broca's area to combine sounds into words and arrange words into sentences. The second step is to understand sentences, which involves Wernicke's *(VERN-ick-ees)* area.

Wernicke's area, which is usually located in the left temporal lobe, is necessary for speaking in coherent sentences and for understanding speech. Damage to this area results in ***Wernicke's aphasia,*** which is a difficulty in understanding spoken or written words and in putting words into meaningful sentences.

For example, a patient with Wernicke's aphasia said, "You know, once in awhile I get caught up, I mention the tarripoi, a month ago, quite a little, I've done a lot well" (H. Gardner, 1976, p. 68). As this meaningless sentence shows, Wernicke's area is critical for combining words into meaningful sentences and being able to speak coherently (Mesulam, 2008).

Due to genetic factors, most right-handers (96%) and a majority of left-handers (70–80%) have Broca's and Wernicke's areas in the left hemisphere. In about 20% of left-handers, the language areas are in either the right hemisphere or both hemispheres (B. Bower, 2002).

Compared to many other animals, humans rely more heavily on visual information, which is processed in the occipital lobe, our next topic.

Occipital Lobe: Functions

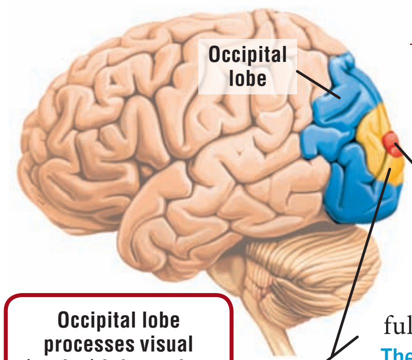
Can you see better than dogs?

Dogs have poor color vision and rely more on their sense of smell. In comparison, all primates, which include monkeys, apes, and humans, have a relatively poor sense of smell and rely more on vision for gathering information about their environments.

If you have ever been hit on the back of the head and saw "stars," you already know that vision is located in the occipital lobe.

The ***occipital lobe*** is located at the very back of the brain and is involved in processing visual information, which includes seeing colors and perceiving and recognizing objects, animals, and people.

Although you see and recognize things with great ease, it is actually a complicated two-step process. Here, we'll give only an overview of that process; we'll go into more detail in Module 5.



Occipital lobe processes visual (seeing) information.

Vision

When you look in the mirror and see your face, you don't realize that seeing your face involves two steps and two different areas in the occipital lobe (Maldonado et al., 1997). The first step in seeing your face involves the primary visual cortex.

The ***primary visual cortex,*** which is located at the very back of the occipital lobe, receives electrical signals from receptors in the eyes and transforms these signals into meaningless basic visual sensations, such as lights, lines, shadows, colors, and textures.

Since the primary visual cortex produces only meaningless visual sensations (lights, lines, shadows), you do not yet see your face. Transforming meaningless visual sensations into a meaningful visual object occurs in the visual association area (Kiernan, 2008).

The ***visual association area,*** which is located next to the primary visual cortex, transforms basic sensations, such as lights, lines, colors, and textures, into complete, meaningful visual perceptions, such as persons, objects, or animals.

When the second step works properly, there is increased activity in the visual association area and decreased activity in the primary visual cortex as basic sensations are turned into meaningful perceptions (S. O. Murray et al., 2002). If there are problems in the second step, the person can still see parts of objects but has difficulty combining the parts and recognizing the whole object (Osborne et al., 2007; Purves et al., 2008).

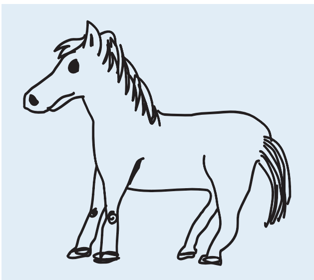
We'll discuss two unusual visual problems that result from damage to association areas.

Visual Agnosia

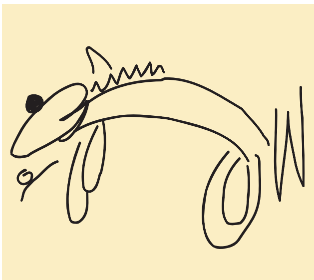
Since the visual association area is critical for recognizing faces, shapes, and objects, damage to this area results in difficulties of recognition, a condition called visual agnosia *(ag-NO-zee-ah).*

In ***visual agnosia,*** the individual fails to recognize some object, person, or color, yet has the ability to see and even describe pieces or parts of some visual stimulus.

Here's what happened when a patient with damage to the visual association area was asked to simply copy an object.



A patient who has visual agnosia was asked to make a copy of this horse, something most everyone can do.



The patient drew each part of the horse separately and could not combine individual parts into a meaningful image.

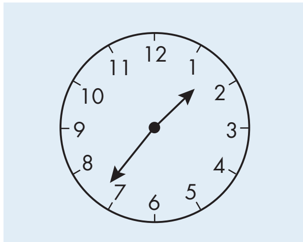
Patients with visual agnosia can see individual parts of an object, such as a horse's leg, but, because of damage to visual association areas, have great difficulty combining parts to perceive or draw a complete and recognizable image, such as a complete horse (Farah, 2004; Maratsos & Matheny, 1994). Damage to association areas can also result in seeing only half of one's world.

Neglect Syndrome

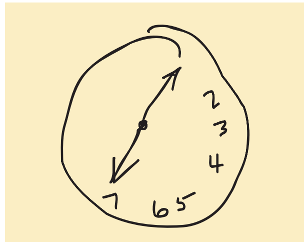
Individuals who have damage to association areas, usually in occipital and parietal lobes, and usually in the right hemisphere, experience a very strange problem called the neglect syndrome.

The ***neglect syndrome*** refers to the failure of a patient to see objects or parts of the body on the side opposite the brain damage. Patients may dress only one side of their body and deny that opposite body parts are theirs ("that's not my leg").

Here's how a patient with neglect syndrome drew an object.



A patient with neglect syndrome caused by right-sided brain damage was asked to copy this clock.



The patient drew only the right side of the clock because he did not see or recognize things on his left side.

After a stroke or other damage, usually to the occipital and parietal association areas in the right hemisphere, patients may behave as if the left sides of objects or their own bodies no longer exist: they may not shave or dress the left sides of their bodies, which they do not recognize. Neglect syndrome shows the important function of association areas in recognizing things (Danckert & Ferber, 2006).

Now we'll journey beneath the cortex and explore a group of structures that existed in evolutionarily very old, primitive brains.

Figure/Text Credits: (bottom left) From "Language Specificity and Elasticity: Brain and Clinical Syndrome Studies," by M. Maratsos and L. Matheny, 1994, *Annual Review of Psychology, 45,* 487–516; (bottom right) Adapted from *Left Brain, Right Brain,* by S. P. Springer and G. Deutsch, 4/e, 1989. W. H. Freeman Company.

E. Limbic System: Old Brain

Structures and Functions

How are you like an alligator?

Your cortex is involved in numerous cognitive functions, such as thinking, deciding, planning, and speaking, as well as other sensory and motor behaviors. But what triggers your wide range of emotional experiences, such as feeling happy, sad, or angry? The answer lies deeper inside the brain, where you'll find a number of interconnected structures that are involved in emotions and are called the limbic system (J. H. Friedman & Chou, 2007; Ropper & Samuels, 2009).

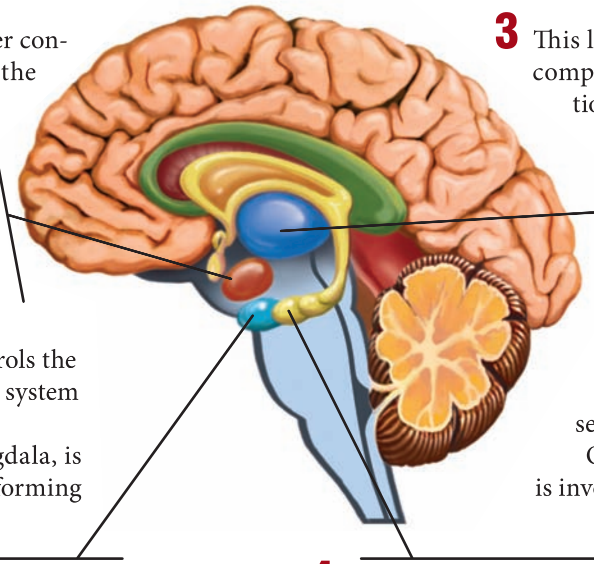
The ***limbic system*** refers to a group of about half a dozen interconnected structures that make up the core of the forebrain. The limbic system's structures are involved with regulating many motivational behaviors such as obtaining food, drink, and sex; with organizing emotional behaviors such as fear, anger, and aggression; and with storing memories.

The limbic system is often referred to as our primitive, or animal, brain because its same structures are found in the brains of animals that are evolutionarily very old, such as alligators. The alligator's limbic system, which essentially makes up its entire forebrain, is involved in smelling out prey, defending territory, hunting, fighting, reproducing, eating, and remembering. The human limbic system, which makes up only a small part of our forebrain, is involved in similar behaviors.

Alligators and humans have limbic systems.

We'll discuss some of the major structures and functions of the limbic system. The drawing below shows the right hemisphere (the left hemisphere is cut away). Notice that the limbic structures are surrounded by the forebrain, whose executive functions regulate the limbic system's emotional and motivational behaviors.

Important Parts of the Limbic System



1 One limbic structure that is a master control for many emotional responses is the hypothalamus *(high-po-THAL-ah-mus).*

The ***hypothalamus*** regulates many motivational behaviors, including eating, drinking, and sexual responses; emotional behaviors, such as arousing the body when fighting or fleeing; and the secretion of hormones, such as occurs at puberty.

In addition, the hypothalamus controls the two divisions of the autonomic nervous system discussed on the next page.

The next limbic structure, the amygdala, is also involved in emotions but more in forming and remembering them.

2 The ***amygdala*** *(ah-MIG-duh-la),* located in the tip of the temporal lobe, receives input from all the senses. It plays a major role in evaluating the emotional significance of stimuli and facial expressions, especially those involving fear, distress, or threat.

When the amygdala is damaged, patients had difficulty recognizing emotional facial expressions and animals did not learn to fear or avoid dangerous situations. Brain scans indicate that the amygdala is involved in identifying emotional facial expressions (Hooker et al., 2006). Researchers report that the amygdala is critical in recognizing emotional facial expressions, including happy faces but especially faces indicating fear, distress, or threat; evaluating emotional situations, especially involving threat or danger; and adding emotional feelings to happy or sad events (remembering a joke, going to a funeral) (R. J. Dolan, 2002).

3 This limbic structure, which is like a miniature computer that gathers and processes information from all of your senses (except smell), is called the thalamus *(THAL-ah-mus).*

The ***thalamus*** is involved in receiving sensory information, doing some initial processing, and then relaying the sensory information to areas of the cortex, including the somatosensory cortex, primary auditory cortex, and primary visual cortex.

For example, if the thalamus malfunctions, you might have difficulty processing sensory information (hearing or seeing).

Our last limbic structure, the hippocampus, is involved in saving your memories.

4 The ***hippocampus,*** which is a curved structure inside the temporal lobe, is involved in saving many kinds of fleeting memories by putting them into permanent storage in various parts of the brain.

For example, humans with damage to the hippocampus have difficulty remembering new facts, places, faces, or conversations because these new events cannot be placed into permanent storage (Rolls, 2007). Think of the hippocampus, which is involved in saving things in long-term storage (see p. 268), as functioning like the "Save" command on your computer.

Limbic system versus frontal lobe. Some of the basic emotional feelings triggered by the limbic system (anger, rage, fear, panic) carry the potential for self-injury or injury to others. Researchers found that our larger and evolutionarily newer frontal lobe, which is involved in thinking, deciding, and planning, plays a critical role in controlling the limbic system's powerful urges (Banks et al., 2007; Rosenkranz et al., 2003).

One particular structure in the limbic system, the hypothalamus, also has an important role in regulating the autonomic nervous system, which we'll examine next.