Module 12

The Cerebral Cortex

Module Learning Objectives

- Identify the various regions of the cerebral cortex, and describe their functions.
- Discuss the brain's ability to reorganize itself, and define neurogenesis.

What are the functions of the various cerebral cortex regions?

Older brain networks sustain basic life functions and enable memory, emotions, and basic drives. Newer neural networks within the cerebrum—the hemispheres that constitute 85 percent of the brain's weight—form specialized work teams that enable our perceiving, thinking, and speaking. Like other structures above the brainstem (including the thalamus, hippocampus, and amygdala), the cerebral hemispheres come as a pair. Covering those hemispheres, like bark on a tree, is the cerebral cortex, a thin superficial layer of interconnected neural cells. It is your brain's thinking crown, your body's ultimate control and information-processing center.

As we move up the ladder of animal life, the cerebral cortex expands, tight genetic controls and rules, and the organism's adaptability increases. Frogs and other small-brain amphibians operate extensively on preprogrammed genetic instructions. The larger cortices of mammals often increased capacities for learning and thinking, enabling them to be more adaptable. What makes us distinctive human mostly arises from the complex functions of our cerebral cortex.

Structure of the Cortex

If you opened a human skull, exposing the brain, you would see a wrinkled organ, shaped somewhat like the meat of an overripe walnut. Without these wrinkles, a flattened cerebral cortex would require triple the area—you'd need to make a large pizza. The brain's left and right hemispheres are filled mainly with axons connecting the cortex to the brain's other regions. The cerebral cortex—that thin surface layer—contains some 20 to 23 billion nerve cells and 300 million synaptic connections (de Courten-Myers, 2005). Being human takes a lot of nerve.

Supporting these billions of nerve cells are nine times as many glial cells (glia cells). Neurons are like queen bees; on their own they cannot feed or shape themselves. Glial cells are worker bees. They provide nutrients and insulating myelin, guide neural communication, and mop up toxins and neurotransmitters. Cilia may also play a role in learning and thinking. By "chatting" with neurons they may participate in information transmission and memory (Fields, 2009; Miller, 2005).

In more complex animal brains, the proportion of glia to neurone increases. A postmortem analysis of Einstein's brain did not find more or larger-than-usual neurones, but it did reveal a much greater concentration of glial cells than found in an average Albert's head (Fields, 2004).

Each hemispheres' cortex is subdivided into four lobes, separated by prominent fissures, or folds (Figure 12.1). Starting at the front of your brain and moving over the top, there are the frontal lobes (behind your forehead), the parietal lobes (at the top and to the rear), and the occipital lobes (at the back of your head). Reversing direction and moving forward, just above your ears, you find the temporal lobes. Each of the four lobes carries out many functions, and many functions require the interplay of several lobes.

Functions of the Cortex

More than a century ago, surgeons found damaged cortical areas during autopsies of people who had been partially paralyzed or speechless. This rather crude evidence did not prove that specific parts of the cortex control complex functions like movement or speech. After all, if the entire cortex controlled speech and movement, damage to almost any area might produce the same effect. As with our power cord cut would go dead, but we would be fooling ourselves if we thought we had "localized" the picture in the cord.

Motor Functions

Scientists had better luck in localizing simpler brain functions. For example, in 1870, German physiologist Gustav Fritsch and Eduard Hitzig made an important discovery. Mild electrical stimulation to parts of an animal's cortex made parts of its body move. The effects were selective: Stimulation caused movement only when applied to an arch-shaped region at the back of the frontal lobe, running roughly ear-to-ear across the top of the brain. Moreover, stimulating parts of this region in the left or right hemisphere caused movements of specific body parts on the opposite side of the body. Fritsch and Hitzig had discovered what is now called the motor cortex.

Mapping the Motor Cortex

Luckily for brain surgeons and their patients, the brain has no sensory receptors. Knowing this, Oskar Foerster and Wilder Penfield were able to map the motor cortex in hundreds of wide-awake patients by stimulating different cortical areas and observing the body's responses.
They discovered that body areas requiring precise control, such as the fingers and mouth, occupy the greatest amount of cortical space (FIGURE 12.2). In one of his many demonstrations of motor behavior mechanics, Spanish neuroscientist José Delgado stimulated a spot on a patient's left motor cortex, triggering the right whose fingers closed despite his best efforts, remarked, "I guess, Doctor, that your electricity is stronger than my will" (Delgado, 1969, p. 114). More recently, scientists were able to predict a monkey's arm motion a tenth of a second before it moved—by repeatedly measuring motor cortex activity preceding specific controlled movements.

**BRAIN-COMPUTER INTERFACES**

By eavesdropping on the brain, could we enable someone—perhaps a paralyzed person—to move a robotic limb? Could a brain-computer interface command a cursor to write an e-mail or search the Internet? To find out, Brown University brain researchers implanted 100 tiny recording electrodes in the motor cortices of three monkeys (Nicolelis & Chapin, 2002; Serfaty et al., 2002). As the monkeys used a joystick to move a cursor to follow a moving red target (to gain rewards), the researchers matched the brain signals with the arm movements. Then they programmed a computer to monitor the signals and operate the joystick. When a nearly the same proficiency as had the mind-reading computer moved the cursor with two monkeys were trained to control a robot arm that could grasp and deliver food (Valiante et al., 2008), and then a human did the same (FIGURE 12.3).
Association Areas

So far, we have pointed out small cortical areas that either receive sensory input or directly control muscle output. Together, these occupy about one-fourth of the human brain’s thin, wrinkled cover. What, then, goes on in the vast regions of the cortex? In these association areas (the peach-colored areas in Figure 12.7), neurons are busy with higher mental functions—many of the tasks that make us human.

Electrically probing an association area won’t trigger any observable response. So, unlike the sensory and motor areas, association area functions cannot be neatly mapped. Their activity has led to what Donald McFarlane (1996, p. 44) has called “one of the hardest words in the garden of psychology”: the claim that we ordinarily use only 10 percent of our brains. (If true, wouldn’t this imply a 90 percent chance that a bullet to your brain would land in an unused area?) Surgically lesioned animals and brain-damaged humans bear witness that association areas are not dormant. Rather, these areas integrate, integrate, and act on sensory information and link it with stored memories—a very important part of thinking.

Association areas are found in all four lobes. The prefrontal cortex in the forward part of the frontal lobes enables judgment, planning, and processing of new memories. People with damaged frontal lobes may have intact memories, high scores on intelligence tests, and great cookie-baking skills yet they would not be able to plan ahead to begin baking a cake for a birthday party (Huay et al., 2006).

Frontal lobe damage also can alter personality and remove a person’s inhibitions. Consider the classic case of railroad worker Thaneus Gage. One afternoon in 1848, Gage, then 25 years old, was packing gunpowder into a rock with a tampering iron. A spark ignited the gunpowder, shooting the rod up through his left cheek and out the top of his skull, leaving his frontal lobes massively damaged (Figure 12.8 on the next page). To everyone’s amazement, he was immediately able to sit up and speak, and after the wound healed he returned to work. But the affable, soft-spoken man was now irritable, profane, and dishonest. This person, said his friends, was “no longer Gage.” Although his mental abilities and memories were intact, his personality was not. (Although Gage lost his job, he did, over time, adapt to his injury and find work as a stagecoach driver [Marzban & Lera, 2010].)

More recent studies of people with damaged frontal lobes have revealed similar impairments. Not only may they become less inhibited (without the frontal lobe brakes on their impulses), but their moral judgments may seem unreasoned by normal emotions. Would you advise pushing someone in front of a runaway boxcar to save five others? Most people do not, but those with damage to a brain area behind the eyes often do (Koenig et al., 2007). With their frontal lobes ruptured, people’s moral compass seems to disconnect from their behavior.
Association areas also perform other mental functions. In the parietal lobes, parts of which were large and unusually shaped in Einstein's normal-weight brain, they enable surgery, stimulation of one parietal lobe area produced a feeling of wanting to move an upper limb, the lips, or the tongue (but without actual movement). With increased stimulation, patients falsely believe they actually have moved. Curiously, when surgeons stimulated but had no awareness of doing so (Desmedt et al., 2009). These head-scanning findings suggest that our perception of moving does not come from the movement itself, but rather from our intention and the result we expect.

Yet another association area, on the underside of the right temporal lobe, enables us to recognize faces. If a stroke or head injury destroys this area of your brain, you would still be able to describe facial features and to recognize someone's gender and approximate age. Nevertheless, we should be wary of using pictures of brain "hot spots" to create a new mental function for kids. Complex connections between the brain areas involved in thinking, speaking, and understanding. Today's neuroscience has shown that language functions are distributed across other brain areas as well. Memory, language, and attention result from the synchronized activity among different brain areas (Knight, 2007). Dot for religious experience. Reports of more than 40 distinct brain regions becoming active in different religious states, such as praying and meditating, indicate that there is no simple "God spot." (Fingelkurts & Fingelkurts, 2009). The big lesson: Our mental experiences arise from coordinated brain activity.

The Brain's Plasticity

To what extent can a damaged brain reorganize itself, and what is neurogenesis?

Our brains are sculpted not only by our genes but also by our experiences. MRI scans show that well-practiced pianists have a larger-than-usual auditory cortex area that encodes piano sounds (Bechter et al., 2006; Pantev et al., 1996). In Unit IX, we will focus more on how experience molds the brain. For now, let's turn to another aspect of the brain's plasticity: its ability to modify itself after damage.

Some of the effects of brain damage described earlier can be traced to two hard facts: (1) Severed neurons, unlike cut skin, usually do not regenerate. If your spinal cord were severed, you would probably be permanently paralyzed. And (2) some brain functions seem prewired to specific areas. One newborn who suffered damage to temporal lobe facial recognition area later remained unable to recognize faces (Fanciullo et al., 2009). But there is good news. Some of the brain's neural circuits can reorganize in response to damage. Under the surface of our awareness, the brain is constantly changing, building new pathways as it adjusts to little mishaps and new experiences.

Plasticity may also occur after serious injury, especially in young children (Koh, 1998). Constraint-induced therapy aims to retrain brains and improve the mobility of a brain-damaged child or even an adult stroke victim (Naish, 2004). By restraining a fully functioning limb, therapists force patients to use the "bad" hand or leg, gradually reprogramming the brain. One stroke victim, a surgeon in his fifties, was put to work cleaning tables, with his good arm and hand restrained. Slowly, the bad arm recovered its skills. As damaged brain functions migrated to other brain regions, he gradually learned to write again and even to play tennis (Dodge, 2007).

The brain's plasticity is good news for those who are blind or deaf. Blindness or deafness makes unused brain areas available for other uses (Amed et al., 2005). If a blind person uses one finger to read Braille, the brain area dedicated to that finger expands as the sense of touch invades the visual cortex that normally helps people see (Barnea-Goraly, 1999, 2001). Constraint-induced therapy also helps explain why some studies find that deaf people have enhanced peripheral vision (Bosworth & Dobbins, 1999). In those whose native language is sign, the temporal lobe area normally dedicated to hearing is still in use. Finally, it looks for other signals to process, such as those from the visual system.

Similar reassignment may occur when disease or damage frees up other brain areas normally dedicated to specific functions. If a slow-growing left hemisphere tumor disrupts language (which resides mostly in the left hemisphere), the right hemisphere may compensate (Thiel et al., 2000). If a finger is amputated, the somatosensory cortex that received its input will begin to receive input from the adjacent fingers, then becomes more sensitive (Fox, 1984).

Although the brain often attempts self-repair by reorganizing existing tissue, it sometimes attempts to mend itself by producing new brain cells. This process, known as
neurogenesis, the formation of new neurons.

neurogenesis, has been found in adult mice, birds, monkeys, and humans (Josefson et al., 2008). These new neurons originate deep in the brain and may then migrate elsewhere and form connections with neighboring neurons (Aimone et al., 2010; Gould, 2007). Master stem cells that can develop into any type of brain cell have also been discovered in the human embryo. If mass-produced in a lab and injected into a damaged brain, might neural stem cells turn themselves into replacements for lost brain cells? Might we someday be able to rebuild damaged brains, much as we reseed damaged lawns? Might new drugs spur the production of new nerve cells? Stay tuned. Today's biotech companies are hard at work on such possibilities. In the meantime, we can all benefit from other natural promoters of neurogenesis, such as exercise, sleep, and nonstressful but stimulating environments (Issa et al., 2007; Pfeiffer et al., 2007; Stemman et al., 2006).

Before You Move On

- ASK YOURSELF
  How have you been dealing with how our brains enable our minds affect your view of human nature?

- TEST YOURSELF
  Try moving your right hand in a circular motion, as if polishing a table. Then start your right foot doing the same motion, synchronized with your hand. Now reverse the right foot motion, but not the hands. Finally, try moving the left foot opposite to the right hand.
  1. Why is reversing the right foot motion so hard?
  2. Why is it easier to move the left foot opposite to the right hand?

Answers to the Test Yourself questions can be found in Appendix E, at the end of the book.

Module 12 Review

- The cerebral cortex has two hemispheres, and each hemisphere has four lobes: the frontal, parietal, occipital, and temporal. Each lobe performs many functions and interacts with other areas of the cortex.
- Gland cells support, nourish, and protect neurons and may also play a role in learning and thinking.
- The motor cortex, at the rear of the frontal lobes, controls voluntary movements.
- The somatosensory cortex, at the front of the parietal lobes, receives and processes body touch and movement sensations.
- Body parts requiring precise control or those that are especially sensitive occupy the greatest amount of space in the motor cortex and somatosensory cortex, respectively.
- Most of the brain’s cortex—the major portion of each of the four lobes—is devoted to uncommitted association areas, which integrate information involved in learning, remembering, thinking, and other higher-level functions.
- Our mental experiences arise from coordinated brain activity.
- To what extent can a damaged brain reorganize itself, and what is neurogenesis?
- If one hemisphere is damaged early in life, the other will pick up many of its functions by reorganizing or building new pathways. This plasticity diminishes later in life.
- The brain sometimes mends itself by forming new neurons, a process known as neurogenesis.

Multiple-Choice Questions

1. Damage to which of the following could interfere with the ability to plan for the future?
   a. Frontal lobe
   b. Temporal lobe
   c. Parietal lobe
   d. Occipital lobe
   e. Somatosensory cortex

2. In general, damage to _______ disrupts speaking, while damage to _______ disrupts understanding of language.
   a. the frontal lobe; the occipital lobe
   b. the temporal lobe; the frontal lobe
   c. the occipital lobe; the temporal lobe
   d. Wernicke’s area; Broca’s area
   e. Broca’s area; Wernicke’s area

3. Stimulation at a point on which of the following may cause a person to report being touched on the knee?
   a. Motor cortex
   b. Cerebellum
   c. Somatosensory cortex
   d. Temporal lobe
   e. Thalamus

4. George can move his hand to sign a document because the _______ located in the _______ lobe of the brain, allows him to activate the proper muscles.
   a. somatosensory cortex; parietal
   b. somatosensory cortex; parietal
   c. motor cortex; parietal
   d. somatosensory cortex; frontal
   e. motor cortex; frontal

5. The most noticeable difference between human brains and other mammalian brains is the size of the _______.
   a. association areas
   b. frontal lobes
   c. glial cells
   d. reticular activating system
   e. visual cortex

6. Cognitive neural prostheses are placed in the brain to help control parts of the body.
   a. motor cortex
   b. auditory cortex
   c. somatosensory cortex
   d. visual cortex
   e. parietal lobe

Practice FRQs

1. Doctors sometimes have to remove a portion of the brain to control life-threatening seizures. Describe what the results of the removal of a portion of the motor cortex would be and explain how this procedure might be affected by brain plasticity.

   Answer
   I point: Removing part of the motor cortex will result in paralysis in the parts of the body associated with the removed tissue.
   I point: Because of brain plasticity, the person’s brain may be able to change and reorganize new pathways based on experience. This is more likely if the person is a child.

2. Anthony attends a high school band concert. First, identify and explain which two lobes of his brain are most important for watching and listening to the concert. Second, explain which lobe of the brain is most responsible for analyzing the music and finding personal meaning.

   (3 points)