Cerebral hemispheres

The cerebral cortex is described as having two ‘halves’, called cerebral hemispheres (see figure 2.4). The cerebral hemispheres are two almost-symmetrical brain structures that appear to be separated by a deep groove (known as the longitudinal fissure) running from the front to the back of the brain. However, the hemispheres are not completely separated; they are connected at several points by strands of nerve tissue. The largest and most important of these strands is called the corpus callosum. The two different hemispheres are referred to respectively as the left hemisphere and the right hemisphere.

The left and right hemispheres not only appear to be alike in overall size, shape and structure, but they also have many of the same functions. Furthermore, the particular part of the hemisphere responsible for each of these functions is located in approximately the same place in each hemisphere. For example, each hemisphere has motor and sensory areas that perform the same motor and sensory functions, each for a different side of the body. The left hemisphere receives sensory information from the right side of the body and controls movements on the right side. The right hemisphere receives sensory information from the left side of the body and controls movements on the left side. In addition to the hemispheres having common functions, each hemisphere also has specialised functions. For example, human language is primarily a function of the left hemisphere, and the right hemisphere is primarily involved in many functions that are not dependent on language, such as spatial and visual thinking and the recognition of faces and tunes.

Corpus callosum

Although there is considerable research evidence that supports specialisation in each of the hemispheres and greater control or ‘dominance’ of one hemisphere in certain functions, the two hemispheres do not function independently. Both hemispheres are involved in virtually everything we think, feel and do, exchanging information and functioning together in an interactive, coordinated way. The interaction between the hemispheres occurs mainly through the corpus callosum.

The corpus callosum is a strand, or ‘bridge’, of nerve tissue that connects the left and right cerebral hemispheres and serves as the main communication pathway between them (see figures 2.5 and 2.6). Its function is one of a ‘cross-over station’ for neural messages between the two cerebral hemispheres. Its many millions of nerve fibres each crossover from one hemisphere to the other, interconnecting corresponding areas of the cerebral cortex. In this way, information can be exchanged between the two hemispheres when performing their many functions as we think, feel and behave throughout everyday life.

Four lobes of the cerebral cortex

The cerebral cortex of each hemisphere can be divided into four anatomical regions called cortical lobes. Cortical lobes are areas of the brain associated with different structures and functions. The four lobes are named after the bones of the skull that cover them: the frontal lobe, the parietal lobe, the occipital lobe and the temporal lobe (see figure 2.7).

The lobes contain areas of cortex that have specialised sensory or motor functions, as well as areas of cortex generally referred to as association cortex. Within the association cortex are different areas commonly called association areas. Each association area has one or more functions that typically involve integrating information from sensory, motor and other brain areas or structures to enable us to think, feel and behave as we do.

The sensory areas of the lobes receive and process information from sensory receptors in the body. Sensory receptors are specialised neurons that detect and respond to a specific type of sensory information. For example, there are specialised sensory receptors for detecting and responding to each type of sensory information from the environment (such as for vision and for hearing).
and sensory receptors for sensory information from the body (such as touch, temperature and muscle movement). Sensory receptors also convert the 'raw' sensory information into neural ('nerve') impulses and transmit it to the sensory areas in the brain via neural pathways (nerves) where it is processed. Different sensory areas are located in different lobes of the brain. The sensory area that receives and processes visual information is called the primary visual cortex. The primary visual cortex is located in the occipital lobe. Auditory information, processed in the primary auditory cortex, is located in the temporal lobe. Sensory information from the skin (about pressure and temperature) and from skeletal muscles (about movement) is processed in the primary somatosensory cortex, located in the parietal lobe. Sensory information is transmitted initially to the primary sensory area specific to that sense.

The motor areas receive and process information about voluntary bodily movements; that is, intentional movements such as when you scratch your nose or pick up a pen and write. There is only one primary motor area in the brain. This is called the primary motor cortex and it is located in the frontal lobe. The primary motor cortex controls our movements by sending neural messages to various parts of the body to make them move in the required way.

The association areas of each lobe integrate information from different brain areas and are mainly involved in complex cognitive (mental) processes such as perceiving, thinking, learning, remembering, reasoning and so on. Unlike the sensory and motor areas, association areas do not have any specialised sensory or motor function. Association areas are located in all four lobes of each hemisphere and may receive and process information from sensory and/or motor areas, as well as from other structures or other association areas of the brain in other lobes.

**Frontal lobe**

The frontal lobe is the largest of the four lobes and occupies the upper forward half of each cerebral hemisphere, right behind your forehead (see figure 2.9).

Located at the rear of each frontal lobe and running roughly across the top of your head is a strip of neural tissue called the primary motor cortex (see figure 2.10). The primary motor cortex is specifically involved in controlling voluntary bodily movements through its control of skeletal muscles. Skeletal muscles are attached directly to bones and include the hand, arm, leg, back and facial muscles. Your skeletal muscles are involved when you smile, wiggle your toes, nod your head and bend to sit in a chair.

**Figure 2.8** Each cortical lobe has areas that specialise in receiving and processing sensory or motor information. There are also association areas that integrate sensory, motor and other information for complex mental processes.

**Figure 2.9** The frontal lobe.

**The primary motor cortex.**

In the forward section of each frontal lobe are association areas that receive information from other lobes to enable us to perform complex mental functions. These association areas are involved when you plan to go out with your friends, when you estimate whether you have enough time to shower and change before someone arrives, when you have to decide which of two items of clothing is the best value for money and when you have to consider the meaning of a term such as 'justice' or 'globalisation' for an essay. The frontal lobes are also involved with personality, the control of emotions and expression of emotional behaviour. Some psychologists refer to the frontal lobe as having an 'executive' role in our thinking, feeling and behaving. This is because it is the end point for a lot of the sensory information received and processed in the other lobes. Furthermore, the frontal lobe coordinates many of the functions of the other lobes, and determines many behavioural responses.

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**Learning Activity 3**

**Mapping the primary motor cortices**

Make a copy of the left primary motor cortex in figure 2.11 using transparent paper. Use this traced copy to make a copy of the left primary motor cortex in your workbook and, next to it, a copy of the right primary motor cortex (by using the reverse side of the traced copy).

Use arrows to identify the specific area(s) of the left and right primary motor cortices that would initiate each of the following voluntary movements:

1. bending your right arm
2. wriggling the toes on your left foot
3. opening your mouth for the dentist
4. sucking on your thumb
5. winking with your right eye
6. clenching your left fist
7. kissing
8. crossing your legs
9. bending your right knee to walk up a step
10. talking
Broca's area

A specific cortical area located in the left frontal lobe next to the motor cortex areas that control the muscles of the face, tongue, jaw and throat is an area called Broca’s area (see figure 2.13).

Broca’s area is thought to be responsible for the production of articulate speech; that is, speech that is clear and fluent. In particular, Broca’s area is involved with coordinating movements of the muscles required for speech and supplying this information to the appropriate motor cortex areas. If you were to read this section of text aloud, Broca’s area would have an important role in coordinating messages to your lips, jaws, tongue and vocal cords to enable you to produce (say) the words clearly and fluently.

Broca’s area is also linked to and interacts with areas of the cerebral cortex that are involved with the meaning of words and the structure of sentences, as well as the specific parts of speech such as adjectives, prepositions and conjunctions. Research indicates that Broca’s area is also involved with understanding the grammatical structure of a sentence that is heard or read in order to extract aspects of meaning that depend on that grammatical structure (Thompson, 2000; Zurif, 1990; Schwartz, 1987). This becomes apparent with speech impairments that result when Broca’s area is damaged (see box 1).

Damage to Broca’s area and effects on speech

Broca’s area is named after Paul Broca, a French doctor whose study of brain-damaged patients led to the finding in 1861 that a relatively small area in the frontal lobe of the left cerebral hemisphere is associated with the production of fluent speech. Broca’s research enabled a better understanding of the role of the brain when we speak.

Damage to Broca’s area often produces speech that is very deliberate, consisting of a few words with a very simple grammatical structure, but damage rarely results in the total loss of speech. Other language abilities that are not dependent on speech, such as reading and writing, appear unaffected when Broca’s area is damaged. The speech impairment is a type of aphasia. Aphasia is a form of language loss or impairment due to brain damage, injury or disease. In Broca’s aphasia (also called non-fluent aphasia or expressive aphasia), speech consists of very short sentences, typically three or four words, and these words are mainly verbs and nouns. The small parts of speech, such as to and the are omitted, as are proper grammatical endings of words such as -ing and -ed. For example, if you were to ask someone with Broca’s aphasia what they did today, they might answer: ‘Went house visit cousins’.

There is also evidence that comprehension of speech can be impaired by damage to Broca’s area. Broca’s aphasia can easily become confused when the usual order of words is changed, especially if the meaning cannot be inferred from individual word meanings alone.

For example, the sentence The boy hugged the girl would probably be understood. But the sentence The girl was hugged by the boy would be confusing to someone with Broca’s aphasia as the meaning cannot be inferred from individual word meanings or by context alone. This occurs because either the boy or the girl might reasonably have been the person initiating the hugging action. A similar sentence structure such as The football was kicked by the boy would not create such difficulty because the meaning attached to individual words in the content assists with comprehension; that is, footballs do not kick boys.
Parietal lobe

The parietal lobe is located behind the frontal lobe and occupies the upper back half of the brain, but not the rear-most area (see figure 2.14). The parietal lobe in each hemisphere receives and processes sensory information from the body and skin senses (called somatosensory information) and other sensory areas in the brain. It also sends information to other areas of the brain.

Located at the front of each parietal lobe, just behind and parallel to the primary motor cortex in the frontal lobe (but separated by a fissure, or ‘groove’), is a strip of cortex called the primary somatosensory cortex (see figure 2.15). The primary somatosensory cortex (also called the primary sensory area and primary sensory cortex) receives and processes sensory information from the skin and body, enabling us to perceive bodily sensations. This sensory information includes touch, pressure and temperature from sensory receptors in the skin, and information about muscle movement and the position of limbs from sensory receptors in the muscles, tendons and joints.

The primary somatosensory cortex in the left parietal lobe receives and processes sensory information from the right side of the body. Likewise, the primary somatosensory cortex in the right parietal lobe receives and processes sensory information from the left side of the body. As shown in figure 2.11 on page 74, different areas of the primary somatosensory cortex are involved with sensations of touch received from specific body parts. Furthermore, the amount of cortex devoted to a particular body part corresponds to the sensitivity and amount of use of the body part (Thompson, 2000). For example, your lips, fingers and tongue, which are very sensitive to touch and frequently used in everyday behaviour, have more cortical space than parts that are less sensitive and used less frequently, such as the back of your legs and your hips. The misshapen appearance of the person called homunculus shown in figure 2.16 reflects this difference in sensory representation.

![Figure 2.15](image)

**Figure 2.15** The primary somatosensory cortex.

Learning Activity 4

**Demonstration—primary motor cortex and primary somatosensory cortex**

The following two activities provide quick ways of helping you understand the sensitivity of your primary motor cortex and your primary somatosensory cortex.

1. **Primary motor cortex.** Try wiggling each of your fingers one at a time. Now try wiggling each of your toes. Note how in figure 2.11 (see page 74) the area of your primary motor cortex is much larger for your fingers than for your toes, which relates to the greater sensitivity and more precise control in your fingers.

2. **Primary somatosensory cortex.** Ask a friend to close their eyes. Using a random number of fingers (one to four), press down on the skin of your friend’s back for one or two seconds and ask your friend to report how many fingers you are using. Now repeat the same procedure on the palm or back of your friend’s hand. Your friend should be much better at guessing the number of fingers used when you’re pressing their hand than when you’re pressing their back. As in figure 2.11, the area of the primary somatosensory cortex is much larger for the hands than for the back, which is reflected in more sensitivity and greater accuracy of detection for finger pressure on the hand.

Adapted from Huffman (2002).

**Box 2**

The sensory world of the platypus

The platypus is an egg-laying mammal that lives in and around streams in eastern Australia (including Tasmania). Because of its ducklike bill and webbed feet, some scientists thought it might be a hoax when the first carcasses were brought to Europe at the beginning of the 19th century.

The platypus is largely nocturnal and dives into murky waters, closing its eyes, ears and nostrils as it hunts for invertebrates including insects, shrimp and crayfish. How it senses its prey remained a mystery until the 1980s, when researchers found that the main sensory organ of the platypus is its bill, which is about 7 cm long in an adult 160 cm long. The bill has about 16 longitudinal stripes of receptors: stripes of touch receptors alternating with touch-electrical receptors (see figure 2.17). As the platypus moves its bill underwater, it can detect prey by both the mechanical ripples and the changes in electrical fields they cause. In keeping with the importance of the bill in locating prey, almost all of the primary somatosensory cortex of the platypus is devoted to the bill, and the primary visual area and primary auditory area are small.
Quieting phantom limbs

Chris Jozefowicz

Dealing with a missing limb is bad enough. But often amputees must also struggle with confusing sensations that seem to indicate that an arm or a leg is still present, or ... can cause disabling pain. To find out why, a team led by Herr Flor, a professor of neuropathology at the University of Heidelberg in Germany, tested people who had had an arm amputated. The results contradict the simple assumption that phantom sensations arise from the same brain pathways that processed sensory information when the limb was intact.

Because of a physiological quirk known as passive stimulation, present in a small fraction of people, Flor was able to deliberately induce phantom sensations in five amputees by stimulating other parts of their body. Previous studies had shown that when phantom sensations amount to pain, the region of the sensory cortex that is active is the one that would normally be operating if the limb were intact. But when Flor induced nonpainful sensations—described by patients as tingling or hot—that same region was not especially active. Instead, two regions thought to be involved with body image were engaged.

One region, the posterior parietal cortex (rear area of the parietal lobe), helps people feel that part of their body is their own, rather than some inanimate thing. The other region processes conflicting sensory or motor information.

'The activation patterns are pretty clear,' Flor says, adding that the findings will help her group try to develop treatments for phantom sensations, possibly electrical stimulation or drugs. As many as 70 percent of amputees suffer some form of phantom pain.

The occipital lobe

The occipital lobe is located at the rear-most area of each cerebral hemisphere; that is, at the back of your head (see figure 2.19).

The occipital lobe is primarily involved in vision. Damage to the occipital lobe can produce blindness, even if the eyes and their neural connections to the brain are normal. Although vision is the main function of the occipital lobe, some areas in the other three lobes also have important visual functions (Thompson, 2000; Kolb & Wishaw, 1996).

The primary visual cortex is located at the base of each occipital lobe and this is where visual information from the two eyes is received and processed. The information comes to the primary visual cortex from visual sensory receptors (called photoreceptors) located on the retina at the back of each eye. The left half of each eye (which receives visual sensory information from the right half of the visual field) sends information only to the visual cortex in the left occipital lobe and the right half of each eye (which receives visual sensory information from the left half of the visual field) sends information only to the visual cortex in the right occipital lobe (see box 3). Neurons in the primary visual cortex are specialised to respond to different features of visual information arriving there; for example, such features as orientation (that is, direction) of a line, and edges, shape, motion and colour. Some neurons respond to specific features (for example, shape or colour), while other neurons respond to two or more features (for example, shape and colour).
Association areas in the occipital lobes also have important roles in vision. These association areas interact with the primary visual cortex in each occipital lobe to select, organise and integrate visual information. They also interact with association areas in the frontal, parietal and temporal lobes to integrate visual information with other information such as memory, language and sounds. This enables visual information to be organised and interpreted in a meaningful way. For example, the frontal lobe (together with the parietal lobe) is involved in spatial reasoning, such as when you try to work out whether a specific piece of a jigsaw puzzle will fit into a particular place in the puzzle. Furthermore, the parietal lobe is involved in visual attention and in determining where objects are, and the temporal lobe is involved in determining what objects are.

**Temporal lobe**

The temporal lobe is located in the lower, central area of the brain, above and around the top of each ear (see figure 2.20).

The temporal lobe in each hemisphere is primarily involved with auditory perception, but also plays an important role in memory, in aspects of visual perception such as our ability to identify objects and recognise faces, and in our emotional responses to sensory information and memories.

The primary auditory cortex in each temporal lobe receives and processes sounds from both ears (see figure 2.21). Each primary auditory cortex has specialised areas that receive and process different features of sound and therefore play vital roles in the identification of sounds. The two main features of sound are frequency (which we perceive as pitch) and amplitude or intensity (which we perceive as loudness). If you were listening to classical music, notes with different frequencies (for example, low pitch or high pitch) and amplitudes (for example, loud or soft) would be processed in different areas of the primary auditory cortex. For example, the deep, low-frequency sound of a bass drum would be received in a different location on the cortex from the high-frequency sound produced by a flute. Each primary auditory cortex is also specialised to process different types of sound. Verbal sounds (such as words) are mainly processed in the primary auditory cortex of the left hemisphere, and non-verbal sounds (such as music) are mainly processed in the primary auditory cortex of the right hemisphere. However, this does not mean verbal and non-verbal information is processed exclusively by one hemisphere or the other—there is some overlap.

As with the other lobes, each temporal lobe also has association areas. Different association areas appear to be involved in memory, including linking emotions with memory and determining appropriate emotional responses to sensory information and memories. People with amnesia (partial or complete loss of memory) are often found to have damage in either or both temporal lobes. For example, the temporal lobes appear to be responsible for receiving, processing and storing memories of facts (semantic memories), how to do things (procedural memories) and personal experiences such as birthdays and holidays (episodic memories). They are also involved in object identification (that is, determining what an object is) and face recognition. Therefore, the temporal lobes play an important role when we make decisions about those features of our environment that we perceive and remember. Damage to a temporal lobe as a result of a stroke or severe blow to the head can leave a person with the ability to describe someone’s facial features, to identify their sex and to judge their approximate age, but without the ability to recognise the person as someone they know, even if it is their mother. This indicates that complex mental functions such as perception and memory are not entirely located in any one specific area, but are represented in many interconnected areas of the entire brain. Face recognition appears to require the temporal lobes, but other memory-dependent abilities, such as determining someone’s sex or age, do not.

**Wernicke’s area**

A specific area in the temporal lobe of the left hemisphere only, next to the primary auditory cortex and connected to Broca’s area (see page 74) by a bundle of nerves, is called Wernicke’s area (Thompson, 2000; Kolb & Wishaw, 1996) (see figure 2.22). Wernicke’s area is involved with comprehension of speech; more specifically, with interpreting the sounds of human speech. When a word is heard, the auditory sensation is processed by the primary auditory cortex of the left temporal lobe, but the word cannot be understood until the information has been processed by Wernicke’s area. It is thought that Wernicke’s area is vital not just for understanding words, but also for locating appropriate words from memory to express intended meanings when we speak or write (Geschwind, 1972).

![Temporal lobe](image1)

**Figure 2.20** Temporal lobe.

![Primary auditory cortex](image2)

**Figure 2.21** Primary auditory cortex.

![Wernicke's area](image3)

**Figure 2.22** Wernicke's area.

![Wernicke's area](image4)

**Figure 2.23** Carl Wernicke (1848–1904) identified an area in the temporal lobe of the left hemisphere that is involved with speech comprehension.
Furthermore, when a word is to be spoken, a 'representation' of it is transmitted to Broca's area in the frontal lobe, which coordinates the muscles needed to produce the sound of the word and supplies this information to the face area of the primary visual cortex (Thompson, 2000). Damage to Wernicke's area causes impairment in understanding and speaking language, a condition known as Wernicke's aphasia (see box 4).

**Box 4**

**Damage to Wernicke's area and the effects on speech**

In 1874, the German doctor Carl Wernicke, after whom Wernicke's area is named, reported that patients with injuries in an area of the left hemisphere of the brain towards the rear of the temporal lobe could speak fluently—that is, they were able to string together a series of words—but what they said was largely meaningless. He also observed that people with damage in this area of the brain had difficulty understanding what others said.

This condition is known as Wernicke's aphasia (also called fluent, sensory or receptive aphasia). Someone with this condition can produce rapid, clearly spoken words and even proper phrases and sequences of words, but what they say is generally meaningless and therefore not considered to be understandable language. Their 'speech' has the correct rhythm and general sound of normal speech, but what is said is odd, conveys little information and sounds like a 'word salad' (Thompson, 2000).

For example, consider the statement made by someone diagnosed with Wernicke's aphasia: 'Mother is away here working her work to get her better, but when she's looking the two boys looking in the other part. She's working another time.' The person is describing a picture of a boy and a girl who are stealing biscuits in the presence of an adult female who is preoccupied with another task (see figure 2.24).

**Figure 2.24**

Biscuit theft picture from the Boston aphasia exam, which is used to assess Wernicke's aphasia.

*Goodglass and Kaplan (1983)*

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**Figure 2.25**

This diagram shows the locations of the four lobes, the sensory and motor areas, and areas of the brain involved in speech production and comprehension.

**Learning Activity 5**

**Matching exercise**

Cover the diagram in figure 2.25. Then, using the diagram below, correctly label the following key structures and areas of the cerebral cortex by number.

- a frontal lobe
- b parietal lobe
- c occipital lobe
- d Broca's area
- e Wernicke's area
- f primary somatosensory cortex
- g primary motor cortex
- h primary visual cortex
- i primary auditory cortex
- j temporal lobe