chapter two

Brain structure and processes

Key knowledge and skills

This knowledge includes:

- the interaction between cognitive processes of the brain and its structure, including:
  - roles of the central nervous system, peripheral nervous system (somatic and autonomic), and autonomic nervous system (sympathetic and parasympathetic)
  - roles of the four lobes of the cerebral cortex in the control of motor, somatosensory, visual and auditory processing in humans; primary cortex and association areas
  - hemispheric specialisation: the cognitive and behavioural functions of the right and left hemispheres of the cerebral cortex; non-verbal versus verbal and analytical functions
  - the role of the reticular activating system in selective attention and wakefulness; role of the thalamus in directing attention and switching sensory input on and off
- contribution of studies to the investigation of cognitive processes of the brain and implications for the understanding of consciousness including:
  - studies of aphasia including Broca's aphasia and Wernicke's aphasia
  - spatial neglect caused by stroke or brain injury
  - split-brain studies including the work of Roger Sperry and Michael Gazzaniga
  - perceptual anomalies including motion after-effect, change blindness, synaesthesia
- the application and use of brain research methods in investigating the relationship between biological and cognitive factors of human behaviours including:
  - direct brain stimulation and transcranial magnetic stimulation (TMS)
  - brain recording and imaging techniques: computed tomography (CT), positron emission tomography (PET), single photon emission computed tomography (SPECT), magnetic resonance imaging (MRI), and functional magnetic resonance imaging (fMRI)
- research methods and ethical principles associated with the study of the brain as outlined in the introduction to the unit.

These skills include the ability to:

- formulate research questions and construct testable hypotheses
- analyse and interpret data, and draw conclusions consistent with the research question
- process and interpret information, and make connections between psychological concepts and theories
- apply understanding, to both familiar and new contexts
- evaluate the validity and reliability of psychology-related information and opinions presented in the public domain
- analyse issues relating to and implications of scientific and technological developments relevant to psychology
- communicate psychological information, ideas and research findings accurately and effectively
- use communication methods suitable for different audiences and purposes
- use scientific language, conventions and referencing of information sources appropriate to the medium of communication.

BRAIN STRUCTURE AND PROCESSES

Nervous system

- Central
  - Spinal cord
  - Brain
- Peripheral
  - Somatic
  - Autonomic
    - Sympathetic
    - Parasympathetic

Brain

- Cognitive processes
- Left and right hemispheres
- Four lobes of the cerebral cortex
- Corpus callosum
- Reticular activation system (RAS)
- Thalamus
- Research into cognitive processes
  - Broca’s aphasia and Wernicke’s aphasia
    - Paul Broca
    - Carl Wernicke
  - Spatial neglect
  - Split brain
    - Roger Sperry
    - Michael Gazzaniga
  - Perceptual anomalies
- Brain research methods
  - Non-imaging techniques
    - Case studies
    - Direct brain stimulation
    - Transcranial magnetic stimulation (TMS)
  - Neuroimaging techniques
    - CT scan
    - PET
    - SPECT
    - MRI
    - fMRI

The human nervous system

Chapter 1 outlined the relationship between our body's physiological function and our conscious experience of the world. We noted that different levels of arousal were accompanied by different physiological states and variations in bodily functions. Changes in our level of consciousness are matched by a change in the specific amount and type of brain activity. So, what is the relationship between the way we experience our world and the way our brain works? Some of the answers to these questions lie in the structure and function of our brain, and the way it works within the nervous system. In order to understand this, we must examine the nervous system before we examine the brain in detail.

The brain is part of the nervous system. We can visualise the brain as the nervous system's engine room – it receives and processes information from the rest of the body and generates responses to it. In recent years, neuroscientists have made rapid advances in identifying those parts of the brain and the nervous system involved in human behaviour. Some believe that nearly everything that makes us who we are can be explained by the functions of the brain and the nervous system.

The nervous system is a complex structure composed of billions of interconnected neurons. A neuron is an individual nerve cell that receives, transmits and processes information. Neurons convey messages to each other so quickly that we are not aware of the many connections and

nervous system
A system of networks of specialised cells (neurons) that connect different parts of the body to each other and the brain via electrochemical signals

neuroscientist
A scientist who studies the brain and the nervous system

neuron
An individual nerve cell that receives, transmits and processes information

A CLOSER LOOK

The neuron

No two neurons are exactly alike, but most have four basic parts. Each consists of a *nucleus*, or control centre, and a *soma*, or cell body, with radiating branches. These branches consist of one *axon* and up to 10 000 other projections, called *dendrites*.

Dendrites are protrusions from the soma that receive messages from other neurons and transmit them toward the soma for processing. Axons are thin fibres that carry messages (in the form of nerve impulses) away from the cell body. Your body has millions of kilometres of axons, most of which end in *axon terminals* (branches) that link with the dendrites and somas of other neurons. These links allow information to pass from neuron to neuron.

The axon terminals of one neuron do not physically connect with the dendrites of another neuron. The *synapse* is the gap between one neuron's dendrites and another neuron's axons. Chemicals released at the synapse, known as *neurotransmitters*, carry messages across the synapse to the dendrite of the receiver neuron. Thus, the neural energy is transmitted from one neuron to another (see Figure 2.1).

Neurons may be specialised to perform particular functions. *Motor neurons* are specialised to convey messages away from the brain to the body's skeletal muscles to produce movement. *Sensory neurons* are specialised to carry messages away from the sensory receptors scattered throughout the body to the brain for processing.

Are neurons the same as nerves? No. Neurons are tiny individual cells. *Nerves* are large bundles of axons and dendrites. You can see nerves without magnification. Many nerves have a whitish colour because they contain bundles of axons coated with a fatty layer called *myelin*. Small gaps in the myelin help nerve impulses move faster. Instead of passing down the entire length of the axon, the nerve impulse leaps from gap to gap. When the myelin layer is damaged, a person may suffer from numbness, weakness or paralysis. This is what happens in multiple sclerosis, a disease that occurs when a person's immune system attacks and destroys myelin.

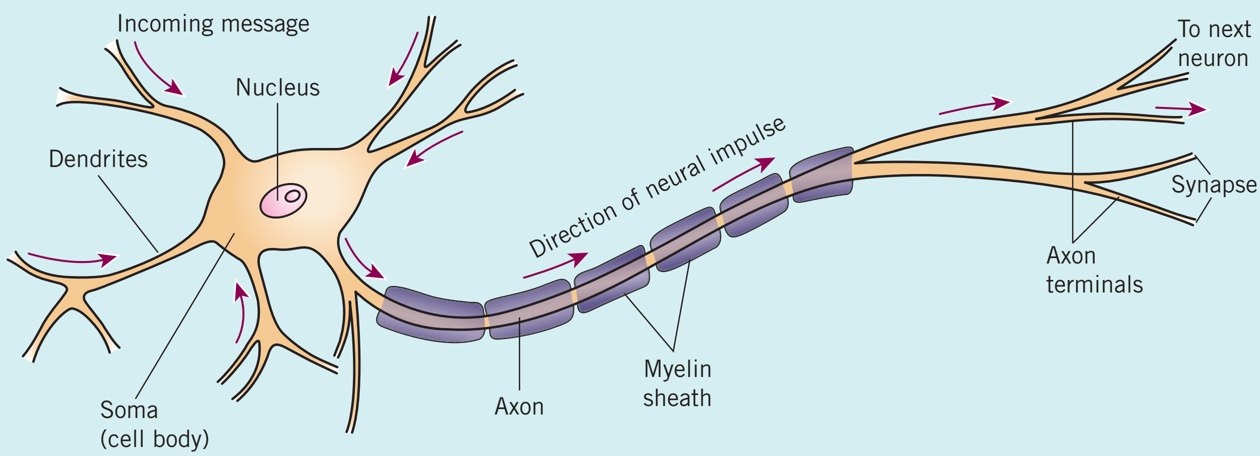


Figure 2.1 A typical neuron showing all its component parts

transmissions involved in even the simplest thought or action. (Make sure you read 'A closer look: The neuron' before going any further. We will also learn more about neurons in chapters 3 and 5.) Neurons are the basic building blocks of the nervous system. A single neuron cannot do very much on its own, but when millions of neurons work together in vast networks, they produce intelligence, consciousness and memory. 'Videolink: Nervous system' shows a graphic overview of the human nervous system.

VIDEO
Nervous system

The nervous system is a hierarchical structure. It is the physiological system we depend on to receive sensory information, process or integrate it, and then transmit motor messages around our body which, in turn, determine our reaction to that information. Figure 2.2 shows an example of this. The information received – a small object offered by a friend – is integrated with what the person knows about the appearance of lollies and dog biscuits, and about whether the friend is a practical joker. The result of this information processing will be a decision to either refuse the object or to reach out for it, while preparing the mouth and stomach to receive food.

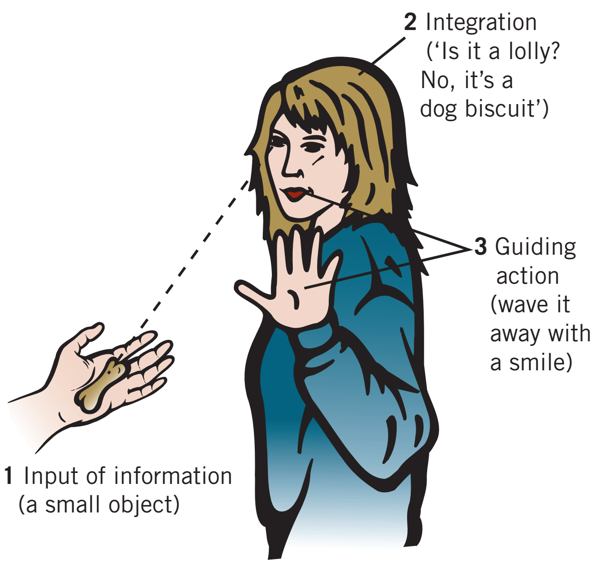


Figure 2.2 The nervous system receives sensory information, processes or integrates it, then transmits motor messages around the body to determine our reaction to that information.

The basis of this whole system is the transmission of electrochemical messages (neural impulses) from neuron to neuron – and the number and frequency of these messages is the key to our level of arousal and state of consciousness, as we shall see later in this chapter.

The nervous system can be divided into two major components or divisions (see Figure 2.3): the *central nervous system (CNS)* and the *peripheral nervous system (PNS)*. Although these divisions are separate physiological structures, their functions are interconnected and both divisions play a significant role in determining our behaviour.

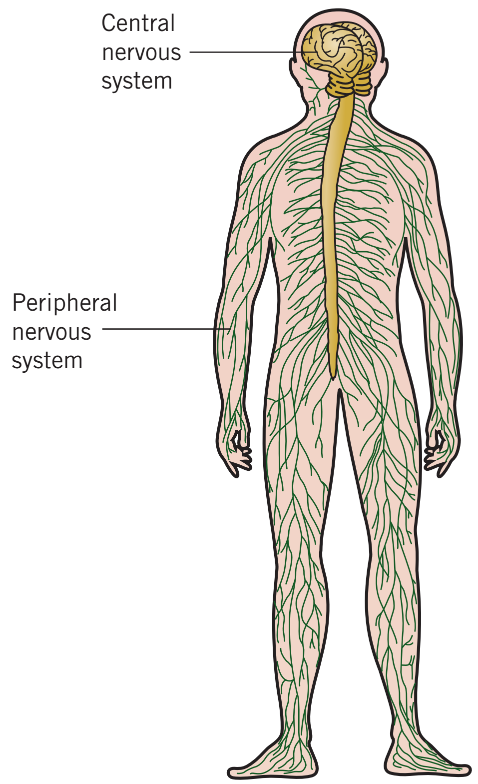


Figure 2.3 Components of the human nervous system

THE CENTRAL NERVOUS SYSTEM (CNS)

The central nervous system (CNS) is composed of the brain and the spinal cord (see Figure 2.4).

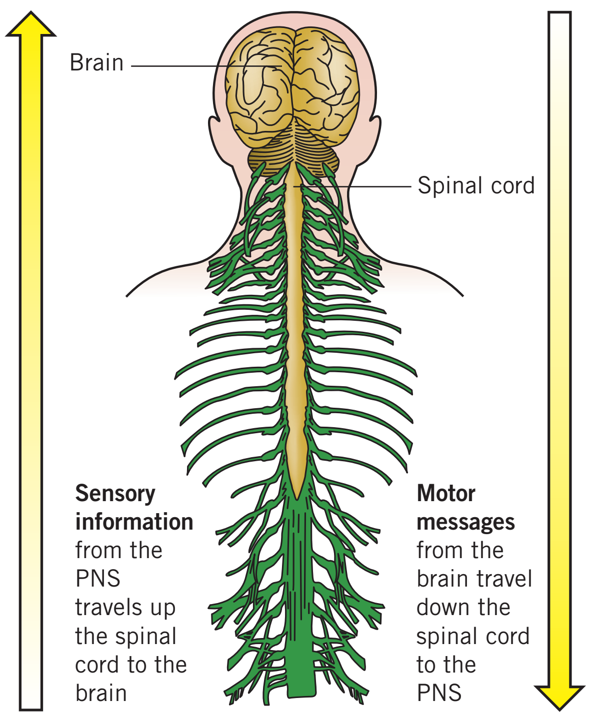


Figure 2.4 The central nervous system – sensory information travels up the spinal cord to the brain; motor messages travel down to the muscles

The spinal cord, an intricate and delicate cable of nerve fibres stretching from the base of the brain to the lower back, connects the brain to the rest of the body via its connection to the peripheral nervous system (PNS) (see below). The spinal cord has two key roles in communicating neural information. First, the PNS *delivers* sensory information to the spinal cord, and the spinal cord's sensory neurons transmit this information up to the brain for processing, in a chain of sensory neurons known as *ascending tracts*. Second, motor neurons in the spinal cord *receive* motor messages from the brain, which it transmits to the PNS and, therefore, to the rest of the body, in a chain of motor neurons known as *descending tracts*. This happens so rapidly and continuously that we are barely aware of it.

If the spinal cord is damaged, the flow of information between the brain and the rest of the body is interrupted. This may result in a loss of sensation in a specific body part or an inability to move a specific body part. For example, damage to the lower section of the spinal cord can result in loss of sensation from, and inability to move, the hips and legs.

THE PERIPHERAL NERVOUS SYSTEM (PNS)

The peripheral nervous system consists of all of the nerves outside the CNS; in other words, all the nerves in the rest of the body (see Figure 2.3). The role of the PNS is to carry sensory information from the rest of the body to the CNS, and motor information from the CNS to the rest of the body. It carries out this role via its connection to the spinal cord.

An example of the way the PNS and CNS work together is when you are running a shower and you put your hand under the stream to test the water temperature. Sensory neurons in your skin register the temperature, and that information is transmitted by the PNS to the spinal cord and on to the brain. The brain then determines whether you need to add more hot or cold water. The brain sends these motor messages via the spinal cord and the PNS to your hand.

Another example is when a musician is tuning her guitar and must listen carefully to the pitch of each string. Auditory information about the sound is transmitted from sensory receptors in the ear via the PNS to the brain, which interprets the pitch. A response (to tighten or loosen the string) is then sent from the brain to the spinal cord and on to the PNS, so that the muscles of the hands and arm can make the action.

We can see, therefore, that the CNS and PNS work together in a smooth and integrated way to enable us to perform everyday functions.

The PNS comprises two subdivisions, which we will now explore.

Figure 2.5 When tuning her guitar, this musician's CNS and PNS are working together to interpret the stimulus and direct the body's muscles in response.

The somatic nervous system

Like all parts of the nervous system, the somatic nervous system (also known as the skeletal nervous system) has a sensory role and a motor role. Its sensory role consists of receiving sensory information from receptor cells located throughout the body and transmitting it inwards to the spinal cord.

central nervous system (CNS)
A major division of the nervous system consisting of all the nerves in the brain and spinal cord

spinal cord
A part of the CNS that consists of a cable of nerve fibres stretching from the base of the brain to the lower back; connects the brain to the PNS and transmits sensory information from the PNS to the brain and motor messages from the brain to the PNS

peripheral nervous system (PNS)
A major division of the nervous system consisting of all the nerves outside of the CNS; transmits sensory information inwards to the CNS and transmits motor messages from the brain outwards to the rest of the body

somatic nervous system
The division of the PNS that transmits sensory information received from sensory receptor cells inwards towards the CNS, and motor messages from the CNS to the body's voluntary skeletal muscles; also known as the skeletal nervous system

The somatic nervous system controls *voluntary* movement through its control of skeletal muscles (muscles attached to bones). It receives motor messages from the CNS and transports them to skeletal muscles in specific body regions so that our responses to stimuli are appropriate. Tying a shoe lace, kicking a football or cleaning your teeth are all voluntary actions that involve the skeletal muscles controlled by the somatic nervous system. For example, when your sensory receptors detect that it is cold, your somatic nervous system may respond by directing you to put on a jumper. This is a voluntary motor response to sensory information.

The autonomic nervous system (ANS)

Imagine that you are strolling along the beach. Your somatic nervous system is controlling the many muscles needed to execute this activity. You are in conscious control of these actions because they are voluntary. Suddenly, a large wave crashes onto the beach, surprising you. Instantly, you jump back from the water. You do not consciously decide to do this; it is not a voluntary decision. This behaviour is due to your autonomic nervous system (ANS).

The ANS contains nerves that are connected to the CNS and the involuntary (or smooth) muscles that control the activity level of our internal organs and glands. By relaying messages between the CNS and our internal systems, the ANS controls all the body's involuntary internal activities that are essential to survival. These activities include heart rate, digestion, kidney function, liver function, glandular activity and perspiration levels.

The word *autonomic* means 'self-governing' and, as the name indicates, the activities controlled by the ANS are mostly automatic. This means they are self-regulating and generally operate independently of the brain, whether we are awake or asleep. For example, you can raise your hand and shade your eyes from bright light because this behaviour is voluntary. The automatic constriction of your pupils to limit the amount of light entering the eye is, however, automatic.

So what is the benefit of the ANS functioning independently? If we are to survive in a constantly changing external environment, we must adapt our behaviour to suit these changes, and we often need to do this quickly. An independent and constantly functioning ANS means that the vital organs and body systems we depend on for physical survival are kept functioning more or less automatically – and without any conscious effort.

Automatic ANS activity also ensures that our changing energy requirements are met and our body is maintained in proper working order according to the demands placed on it. The ANS energises us so we are aroused when we need to be, and lowers our arousal level when less energetic behaviour is required.

By automatically regulating the activity level of survival-related internal systems, the ANS leaves our mind free to focus on important external or internal stimuli. Can you imagine what might happen if you were sitting your final Psychology exam and, at the same time, you also had to concentrate on controlling your heartbeat and remembering to breathe?

Although the ANS acts independently from the brain in many ways, it does still supply information to the brain and receive some commands from it. Some ANS neurons have long fibres through which motor messages are sent. These motor messages regulate the activity level of involuntary muscles, internal organs and glands, and return information to the brain about their activity level. Other ANS neurons are directly connected to the CNS. For example, if you are wakened by shouts of 'Fire!', sensory neurons in your ears send a message to your brain. Your brain interprets this to mean danger and sends an emergency command to the ANS. The ANS then springs into action, arousing you through its various connections to the involuntary muscles that control the internal organs and glands. This is why you have the extra energy needed (often in the form of an adrenalin rush) to leap out of bed and run to safety.

We can also practise certain techniques to influence the ANS. At times when you have wanted to remain calm, you may have exercised some conscious control over your breathing rate; you may even have practised meditation or other forms of relaxation and deliberately slowed your heart rate. Additionally, you may have 'forced' yourself to stop blinking for a period of time. Because it is possible to consciously influence the functioning of the ANS, these techniques are often used to reduce stress, to rehabilitate the body after injury or surgical operations and to relieve depression, among other things. 'Try it yourself 2.1' gives you the opportunity to try to control your ANS.

The ANS can be further divided into two subdivisions, which we will explore next: the *sympathetic nervous system* and the *parasympathetic nervous system*.

TRY IT YOURSELF 2.1

Take some time out – meditation

For this activity you will need a watch with an alarm, a guided meditation tape or a CD of slow music or soothing sounds, a quiet space where you will not be disturbed and lights off or blinds drawn. (You may wish to use the guided meditation track you obtained for the Assessment task in chapter 1.)

During the 30 minutes before you begin your meditation, while you are engaged in normal activity, record your heart rate at 10-minute intervals and work out an average.

Now, set your alarm to a low tone so that it will ring in 20 minutes, turn on your tape (not too loud), arrange yourself in a comfortable position on the floor, close your eyes and relax.

Make a conscious effort to block out all sounds so that you are only listening to the music or guided meditation. While you do this, concentrate on slowing your breathing and relaxing all your muscles. If you are listening to music and not a guided meditation, focus your thoughts on the image of a beautiful location (perhaps a beach at sunset or a rainforest). Once this image is clear, imagine yourself wandering in this place and concentrate only on the sensations you are experiencing there, such as smells, sounds, tastes, sights and feelings.

When your alarm rings, do not open your eyes. Slowly re-establish yourself by focusing on the smells, sounds, tastes, feelings and thoughts that you are experiencing in your actual physical location. Open your eyes and slowly rise from the floor. Turn off the tape.

Now, take your heart rate and compare it with your average prior to the meditation. Is there any difference? If so, how can you account for this? If you have been able to slow your heart rate, you have been able to control a process governed by your ANS.

CHECK YOUR UNDERSTANDING 2.1

1 Use the terms to complete the sentence.
- spinal cord
- brain
- transmit
- movement

The two major functions of the nervous system are to ______________________ sensory information to the ____________ via the ______________________, and relay information about _______________ to the muscles of the body.

2 Match each term with its definition.

a Cognition	i Any processes that involve thinking, knowing or mentally manipulating information
b Cognitive processes	ii An individual nerve cell that receives, carries and processes information
c Central nervous system	iii Thinking, knowing or mentally processing information
d Peripheral nervous system	iv The division of the nervous system composed of the brain and the spinal cord
e Neuron	v The division of the nervous system that carries sensory information to, and motor information from, the central nervous system

3 Indicate whether the following statements are true (T) or false (F).

a The CNS has three major divisions.

b The CNS is composed of the somatic nervous system and the peripheral nervous system.

c The autonomic nervous system regulates the activity of your involuntary muscles, internal organs and glands.

d The spinal cord carries incoming sensory information to the brain and outgoing movement messages from the brain to the rest of the body.

e The spinal cord is responsible for analysing sensory information.

4 In the following scenario, match each underlined action with the correct statement below.

Flavio is walking home after a night at his friend's home. Passing the local park, he hears a sudden loud noise, and <u>his heart rate quickens</u>. <u>He looks around</u> for what has made the noise and then <u>starts to run as fast as he can</u> towards his own street. At the door of his house, he stops and realises his heart is racing and he is out of breath. He <u>takes a deep breath, counts to 10</u> and, when he feels calm again and his heart rate has slowed, he puts the key in the lock.

a The central nervous system and the peripheral nervous system are interdependent.

b The autonomic nervous system acts independently.

c The somatic nervous system controls our voluntary actions through its control of our voluntary skeletal muscles.

d We can consciously control some autonomic nervous system functions.

5 Which division of the PNS (somatic or autonomic) is at work during each of the following actions?

a You sneeze in response to dust

b The sun comes out and you put on your sunglasses

c The sun comes out and your pupils constrict

d You sweat when it gets hot

e You roll up your sleeves when it gets hot

THE SYMPATHETIC NERVOUS SYSTEM: READY FOR ACTION!

In many ways, the sympathetic nervous system is the body's 'emergency' or 'arousal' system. This is the branch of the ANS that dominates during times of high emotion or intense physical activity. The sympathetic nervous system mobilises the body's internal resources to provide

autonomic nervous system (ANS)
The division of the PNS that transmits motor messages from the brain to the body's internal organs and glands, which results in involuntary activity of internal organs and glands, and transmits messages back to the brain about the activity level of these organs and glands

sympathetic nervous system
The branch of the ANS that alters the activity level of internal muscles, organs and glands to physically prepare our body for increased activity during times of high emotional or physical arousal

the extra energy we need for vigorous action, especially in times of stress or threat. Just as a car's accelerator pumps more petrol through the engine to create energy for the car to move faster, the sympathetic nervous system changes the activity level of our internal systems so we have a sudden increase in our energy levels when needed.

How does the sympathetic nervous system prepare us for action? When the sympathetic nervous system dominates, it does many things at once. It activates the body for emergency action by increasing the activity level of some bodily systems while others are slowed down. In this way it arouses us and prepares the body for emergency action, such as fighting or running away. This emergency reaction is referred to as the 'fight–flight response', and we explore this in more detail in 'A closer look: Fight or flight – our emergency response system'.

A CLOSER LOOK

Fight or flight – our emergency response system

Physiological changes in response to a perceived threat begin when a motor message is sent to the adrenal glands. This stimulates them to release the stress hormones adrenalin and noradrenalin into our bloodstream. This rush of hormones increases our heart rate and blood pressure, causing the blood carrying the adrenal hormones to move around our body at a fast rate. When this happens, various other systems are activated. Fats and sugars are released into the bloodstream for additional energy. Our heart rate and breathing rate quicken, and this gives us the extra oxygen needed to convert the released fats and sugars to energy.

This energy-charged blood is quickly carried to our skeletal muscles, enabling them to move at a fast rate. Although we may feel very alert, our mouth feels dry because the activity level of our salivary glands has slowed. Our sweat glands produce more perspiration and our bladder and bowels relax. At the same time, we are unaware that our digestion slows as our stomach decreases its contraction rate. Blood flow to skeletal muscles increases but decreases in the skin to reduce bleeding, and our pupils dilate to allow extra light to enter the eye so we can see better.

By initiating these changes and regulating internal activity, the sympathetic nervous system energises us and physically prepares us for action: to stay and 'fight' the situation or to engage in 'flight' by running away to safety.

What happens if the sympathetic nervous system stays 'switched on' for a long time? If this happens, then we experience stress (see chapter 7). Because stress is actually a state of intense arousal, when we experience stress our internal systems operate at abnormally high levels. If we remain stressed for a prolonged period, we are in danger of developing a range of physiological and psychological disorders that could lead to a complete breakdown.

THE PARASYMPATHETIC NERVOUS SYSTEM: KEEPING US CALM

If the sympathetic nervous system prepares us for action, what does the other division of the ANS – the parasympathetic nervous system – do? Once the need for high arousal has passed, the parasympathetic nervous system reverses the effects of the sympathetic nervous system. This reversal returns our body to its normal level of arousal, or a more relaxed state that is appropriate when the period of high emotion or need for physical activity has passed. Our heart and breathing rates, the level of sugar and fats in our bloodstream, the size of our pupils, our blood pressure and digestion rate and so on all return to their normal levels of activity. In this way, the parasympathetic nervous system acts like our car's brakes. We apply the brakes when we want our car to slow down, and the parasympathetic nervous system usually dominates when we need to be less energised or active.

Do we benefit from the domination of the parasympathetic nervous system? In maintaining vital functions such as heart rate, breathing rate and digestion at normal levels, the parasympathetic nervous system plays a major role in keeping us in a state of well-being, or homeostasis. Homeostasis refers to our balanced and healthy state and, luckily, this is the physiological state that we spend most of our time enjoying.

You may have noticed that you take longer to calm down than to become aroused. This is because the parasympathetic nervous system's response is slower than that of the sympathetic nervous system. Increased levels of adrenalin and other hormones needed for sudden increases in activity are quickly activated by the sympathetic nervous system. But although they instantly enter our bloodstream, they take some time to disappear. Therefore, the effects of the parasympathetic nervous system are not experienced until some time after the need for extra energy has disappeared. That is why increased heart rate, muscle tension and other signs of arousal may not fade for 20 or 30 minutes after you feel an intense emotion (such as fear) or engage in increased physical activity.

We have learnt that, depending on whether the sympathetic or parasympathetic system is activated, organs, muscles and glands will respond in a particular way. Though both of these divisions are always active, one usually dominates, functioning similarly to the accelerator and brakes on a car. Figure 2.6 shows a summary of how some organs are activated by each division of the ANS. Table 2.1 provides a more comprehensive overview of these and other responses.

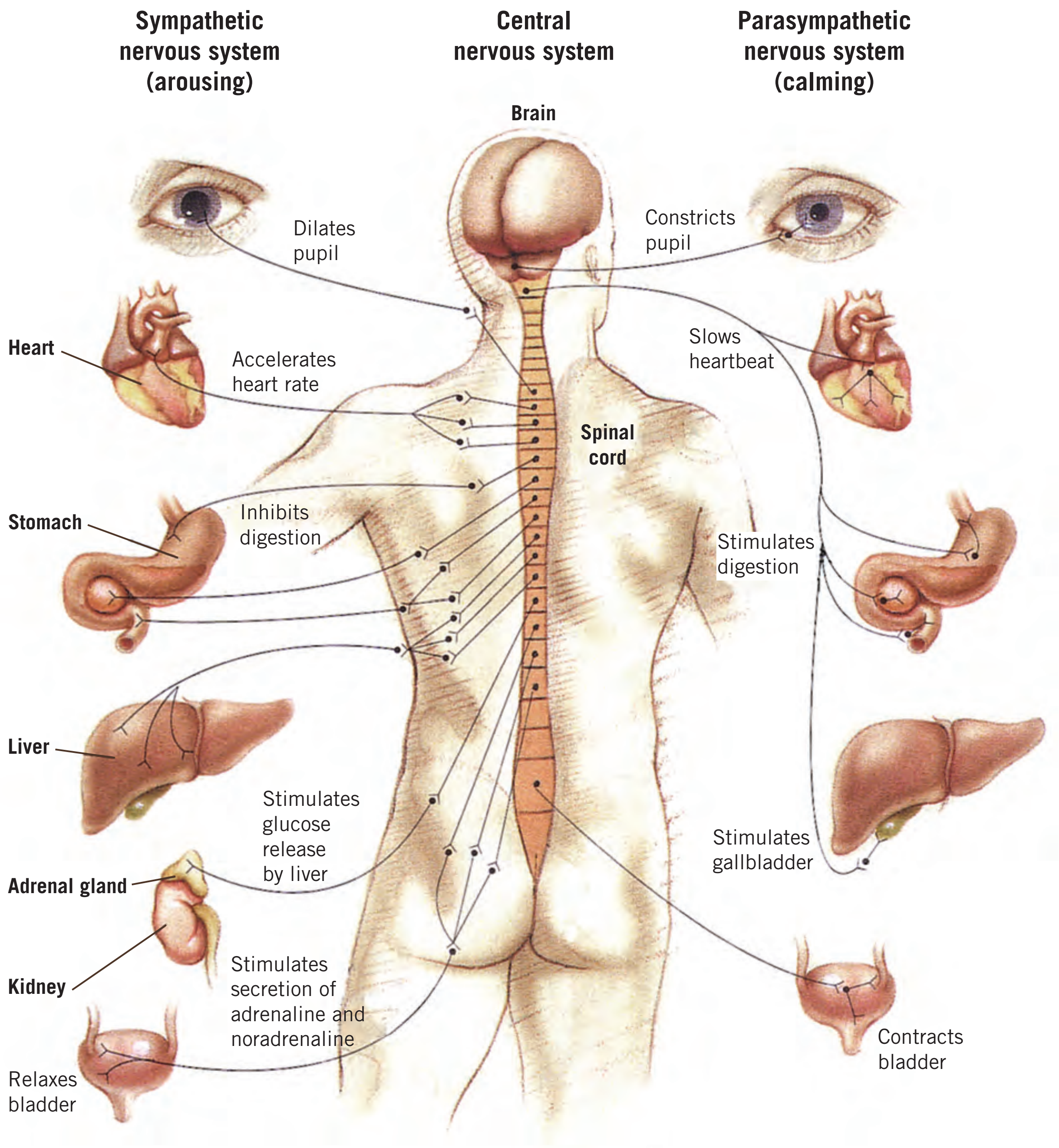


Figure 2.6 The sympathetic and parasympathetic divisions of the ANS have different effects on organs to arouse and extend energy or calm and conserve energy as necessary.

parasympathetic nervous system
The branch of the ANS that maintains an energy level appropriate for normal bodily functioning and physically calms us after high arousal by reversing the changes in bodily functioning caused by the domination of the sympathetic nervous system

homeostasis
The body's balanced and healthy state

Table 2.1 Physiological responses to activation of the sympathetic and parasympathetic nervous systems

SYMPATHETIC RESPONSE	BODY ORGAN	PARASYMPATHETIC RESPONSE
Releases hormones (adrenalin and noradrenalin) to stimulate or repress activity of internal organs	**Adrenal glands attached to kidneys**	Decreases hormone activity
Increases heart rate and pumps blood faster	**Heart**	Decreases heart rate to normal functioning
Increases expansion and rate of oxygen production; relaxes the airways	**Lungs**	Decreases oxygen production; constricts airways
Produces and releases increased level of sugar	**Liver**	Returns to normal functioning
Decreases contractions and slows digestion	**Stomach**	Returns to normal functioning
Decreases production of saliva	**Salivary glands**	Normal production of saliva
Increases perspiration	**Sweat glands**	Inhibits perspiration
Increases production of bile	**Gall bladder**	Inhibits production of bile
Dilates pupils to take in more light	**Eyes**	Constricts pupils; gives near vision
Slows contraction rate and relaxes	**Bladder**	Returns to normal functioning
Stimulated	**Sex organs**	Unstimulated

An overview of the divisions of the human nervous system and how they link together is shown in Figure 2.7.

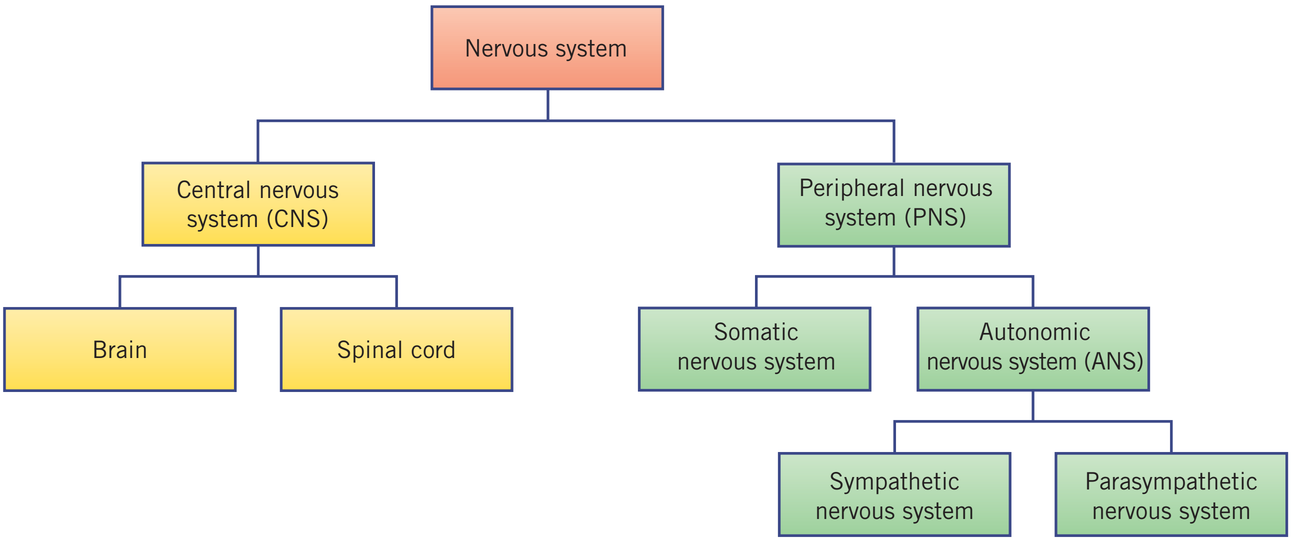


Figure 2.7 The divisions of the nervous system

CHECK YOUR UNDERSTANDING 2.2

1 Choose the best answer to complete the sentence. The autonomic nervous system is important because it:

- **A** allows us to control our skeletal muscles.
- **B** ensures our vital bodily functions operate automatically.
- **C** allows us to respond quickly and automatically to a challenge or threat.
- **D** calms our body after a stressful experience.

2 Identify the division of the autonomic nervous system (sympathetic or parasympathetic) that is most at work during the following situations.

- **a** Your breathing rate slows after you do 20 star-jumps
- **b** Your pupils dilate when you become scared
- **c** Your pupils return to normal size when you are no longer scared
- **d** Your heart rate increases when you go for a jog

3 Which of the following is *not* likely to occur when the sympathetic nervous system is dominating?

- A Dry mouth
- B Increased heart rate
- C Increased respiration rate
- D Decreased perspiration
- E Pupils dilate

4 While playing in the grand final of the netball season, Tia is likely to be experiencing a high level of arousal. Match each of the features she is likely to be experiencing (a–d) with its function (i–iv).

a Increased heart rate	i Increased energy for muscles to act
b Increased respiration	ii Moves glucose and oxygen around the body quickly
c Liver releases sugars	iii Cools the heated body
d Increased perspiration	iv More oxygen to convert sugars to energy

5 Following the grand final, Tia is likely to want to calm her body down. Which of the following statements is true about this process?

- A It will take longer for her parasympathetic nervous system to slow functions down than it took the sympathetic nervous system to arouse them.
- B Her heart rate will drop quickly.
- C Her pupils will constrict.
- D She will decrease her production of saliva and increase perspiration.

Structure and function of the human brain

The human brain is a remarkable organ. It is responsible for most of what makes us who we are: how we think and feel, how we perceive and react to the world around us, and how we construct our sense of who we are. These key human characteristics are the result of the cognitive processes of the brain. Cognition is thinking, knowing or mentally processing information, and cognitive processes are any processes that involve thinking, knowing or mentally manipulating information.

Structurally, the brain can be subdivided into three main regions: hindbrain, midbrain and forebrain. Each region has its own function and each is vital for everyday functioning and information processing.

The *hindbrain* is an important part of the ANS. Located at the base of the brain near the back of the skull, the hindbrain is often referred to as the brain stem. It controls basic survival functions, such as heart rate, breathing, sleep and arousal, and it coordinates voluntary muscle movement and reflexive actions such as coughing, swallowing and vomiting. These functions all occur without any conscious effort.

The *midbrain* is the area of the brain between the hindbrain and the forebrain. Midbrain structures and systems help to keep us alert, awake and vigilant.

The *forebrain*, located above the midbrain and divided into two hemispheres, is the largest and most highly developed part of the brain. It contains a variety of structures that are responsible for our most complex processes, including emotions, motivations, sensations, perceptions, learning, memory and reasoning. It also contains two distinct areas. One contains the thalamus and structures involved in arousal (see pages 60–1) and the other contains the cortex.

Weighing approximately 1.5 kilograms, the human brain may seem tiny compared to that of other animals – that is, until we compare brain weight to body weight. An elephant's brain is one thousandth of its body weight and the ratio for sperm whales is 1 to 10 000; in humans, however, the ratio is 1 to 60. So, for our size, the human brain is pretty impressive – and what it can do sets us apart from other animals.

THE CEREBRAL CORTEX

Considering what it's capable of, we can see that the human brain is highly developed. There are approximately 100 billion neurons in the adult human brain, and an almost infinite number of synaptic connections between them. As we move from lower-order (for example, fish or snails) to higher-order animals (for example, chimpanzees or apes) (see Figure 2.8) we find that an ever-increasing proportion of the brain is devoted to the cerebrum – two large hemispheres (cerebral hemispheres) that cover the upper part of the

cognitive processes
Brain processes that involve thinking, knowing or mentally manipulating information

cognition
Thinking, knowing or mentally processing information

sensation
The immediate response in the brain caused by excitation of a sensory organ

cerebrum
The two large hemispheres that cover the upper part of the brain

cerebral hemispheres
The two halves of the cerebrum that cover the upper part of the brain

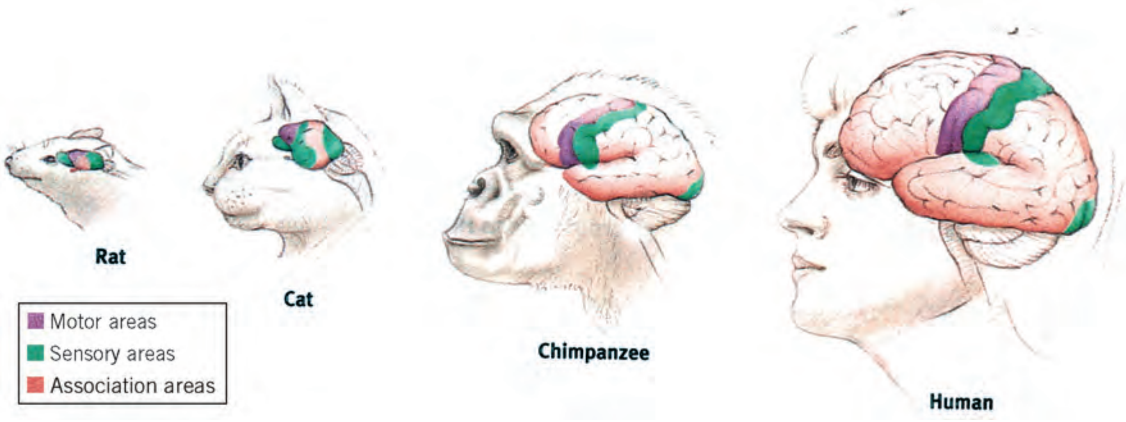


Figure 2.8 The human brain compared to that of lower-order animals. Animals higher up the evolutionary scale have larger areas of cerebrum and are able to perform more complex functions.

brain. (The two cerebral hemispheres – left and right – will be examined in detail later in this chapter.) The outer layer of the cerebrum is known as the cerebral cortex. Although this cortex is only three millimetres thick, it is the largest brain structure and it contains approximately 70 per cent of the neurons in the central nervous system. Without the cerebral cortex, humans would not be any more intelligent than lizards.

The cerebral cortex looks a little like a giant, wrinkled walnut. It covers most of the brain with an outer layer of grey matter (spongy tissue made up mostly of cell bodies). The cortex in lower-order animals is small and smooth. In humans, it is highly convoluted (folded) and is the largest brain structure. These folds increase the cortex's surface area and, naturally, the number of neurons and neural connections possible. In fact, if you spread the thin

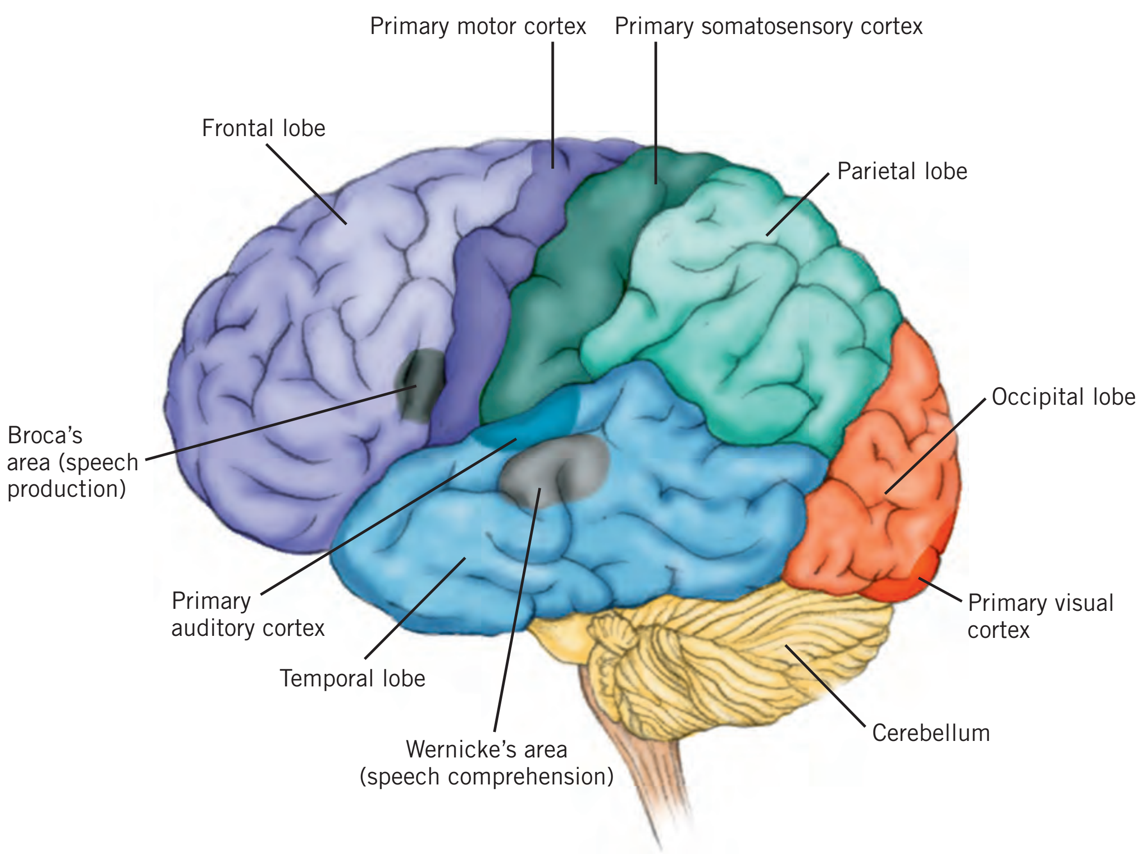


Figure 2.9 The brain, showing all four lobes, sensory and motor cortex areas and language centres

layer of cortex out flat, it would cover an area of more than half a square metre. (That's the seat area of a large armchair.) The fact that humans are more intelligent than other animals is related to the large surface area of the human cortex.

So, does having a larger brain make a person smarter? There is a small variation in brain size among individuals and a small positive correlation exists between intelligence and brain size (Flashman et al., 1997; Rushton, 1995; Wickett, Vernon & Lee, 1995). However, it is a mistake to think that size alone determines human intelligence. A person with an average-sized brain could be extremely intelligent, and someone with a very large brain could have average intelligence. Intelligent behaviour is based on what you know and how efficiently you use your mental capacities, not just the size of your brain.

The cerebral cortex is divided into several *lobes*. These are areas bordered by major fissures and defined by their functions. The *frontal lobe*, *parietal lobe*, *temporal lobe* and *occipital lobe* are all named according to the particular bones of the skull under which they lie. The lobes of the brain are shown in Figure 2.9. These lobes and other areas will be explored next.

The frontal lobes

The frontal lobes, located on the upper front half of each hemisphere, are the largest of the lobes. Cortical areas known as association areas cover the front of each lobe. Association areas are found throughout the cerebral cortex and they do not have a specific sensory or motor role. Their role is to integrate information received from other brain areas or structures. Association areas in the frontal lobe give meaning to the information they integrate, and determine an appropriate response. In doing so, they are the area of the frontal lobe responsible for our most complex mental behaviours, such as planning, problem-solving, thinking, memory, learning and analysing.

The frontal lobes are also responsible for the control of voluntary movement. An arch of tissue at the rear of the frontal lobe that extends over the top of the brain, called the primary motor cortex, directs the body's skeletal muscles; therefore, it controls voluntary movement. If the primary motor cortex is stimulated with an electrical current, various parts of the body twitch or move, depending on which cortical area was stimulated. The left frontal lobe's primary motor cortex controls voluntary movement for the right side of the body and the right frontal lobe's primary motor cortex controls voluntary movement for the left side of the body. This is known as a *contralateral* form of organisation.

Different parts of the body are represented at various locations on the motor cortex, but the amount of motor cortex devoted to each body part corresponds to the importance of bodily areas, not to their size. Figure 2.10 shows a homunculus of the motor cortex – a pictorial representation of the portion of the brain responsible for different anatomical functions. In Figure 2.10, the hands, for example, are represented by more area than the feet. If you've ever wondered why your hands are more dexterous than your feet, it's partly because a larger area of motor cortex is devoted to the hands. You will also notice in Figure 2.10 that a large area of motor cortex is devoted to the lips, mouth and tongue. This is hardly surprising, since dozens of muscles are involved in the production of simple speech! Figure 2.10 also shows you that the parts of the body are represented on the cortex in the opposite position to where they are located on the body. For example, the face and mouth are located towards the bottom of the motor cortex, while the feet and legs are towards the top.

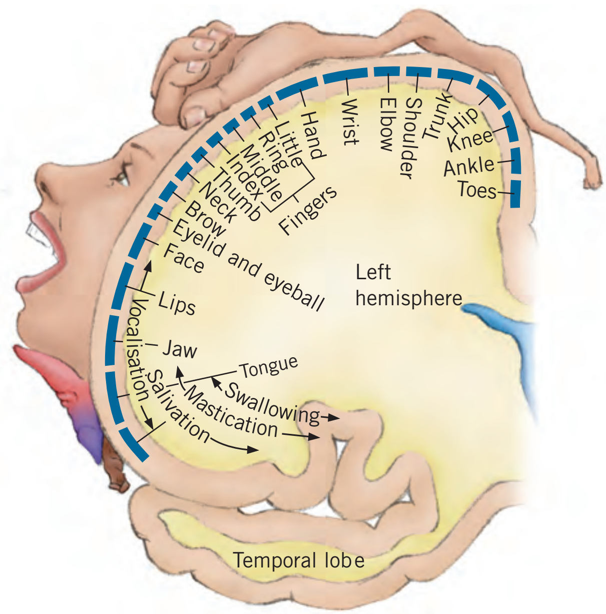


Figure 2.10 The location and size of various representations of body parts along the primary motor cortex are drawn in this motor homunculus so as to correspond to the number of muscles involved in the movement of that body part.

cerebral cortex
The thin layer of tissue that forms the outer layer and surface of the brain's cerebrum; responsible for basic sensory and motor functions, as well as higher mental processes

frontal lobe
The upper front half of each cerebral hemisphere; associated with complex mental abilities and the control of voluntary movement

association areas
All the areas of the cerebral cortex that do not have a specialised sensory or motor function; they integrate information received from different brain areas and structures to enable complex mental behaviours

primary motor cortex
An area at the rear of the frontal lobe that directs the body's skeletal muscles and controls voluntary movement

The left frontal lobe contains an important language centre. Broca's area (identified by Paul Broca) is located in the left frontal lobe close to the primary motor cortex (see Figure 2.9). Broca's area directs the area of the primary motor cortex that controls muscles of the throat, mouth, jaw, tongue and face. By controlling the movement of these muscles, Broca's area is primarily responsible for the production of articulate (clear and fluent) speech. It is also involved in the structure of sentences and analysing the grammar of sentences. If Broca's area is damaged, a person may be unable to produce clear and articulate speech. Research into behaviour controlled by Broca's area is described later in this chapter.

Psychologists believe that the frontal lobes are also heavily involved in emotional behaviour and personality. If the frontal lobes are damaged, an individual's personality and emotional life may change dramatically. Case studies of individuals suffering frontal lobe injury from accidents, brain tumours or accidental poisonings provide much valuable information about the structure and function of the human brain.

'A closer look: The remarkable case of Phineas Gage' examines how a brain injury can result in behavioural changes. 'Focus on research: How the mind senses movement' examines a study into how the brain senses the body's movement.

A CLOSER LOOK

The remarkable case of Phineas Gage

One remarkable case that illustrates the effects of damage to the frontal lobe was reported by Dr J. M. Harlow (1868). Phineas Gage was a young foreman on a railway work crew. He was using a long steel rod (just less than 1.1 metres long) to ram gunpowder into a rock that was blocking the way of the railroad. The rod rubbed the side of the rock, causing a spark that ignited the gunpowder. As a result, the six-kilogram rod was blown right through the side of Gage's head, and through the front of his brain (see Figure 2.11). Amazingly, he survived the accident, and within two months Gage could walk, talk and move normally. But the injury forever changed his personality. Instead of the honest, dependable worker he had been before, Gage became a surly, uncaring, foul-mouthed liar. He eventually left his railway job and spent the rest of his life as part of a travelling side show.

Reasoning or planning may also be affected by damage to the frontal lobe. Patients with frontal lobe damage often get 'stuck' on mental tasks and repeat the same wrong answers over and over (Goel & Grafman, 1995). Drug use may also damage this important area of the brain (Liu et al., 1998).

Figure 2.11 The path of the rod that went through Phineas Gage's skull and brain

FOCUS ON RESEARCH

How the mind senses movement

Lifting a finger is easy. What is far more difficult is understanding how our brain senses that the finger has been moved. For more than a century scientists have struggled to understand which parts of the nervous system allow the body to sense its own position in space. However, Simon Gandevia and colleagues at the Prince of Wales Medical Research Institute in Sydney have devised a technique that clearly demonstrates that the brain only has to send a command to a limb to create the sensation of movement. Their discovery goes some way to resolving the enigma of whether motor commands or receptors in the skin, joints and muscles are more important for creating a feeling of movement.

Gandevia's team studied eight volunteers, by either anaesthetising their forearm and hand, or restricting the flow of blood to the limb. Both techniques deadened sensation to the extent that the volunteers felt they had a 'phantom' hand with fingers clenched, though in fact their fingers were fully extended. When they were asked to flex or extend their wrists, they consistently reported that the position of their hand had changed, in the direction of their efforts, even though it did not move. When they were asked to increase their efforts, the perceived change also increased.

'We have used a simple method to show definitively that the motor command on its own can produce a dramatic illusion in every subject,' Gandevia says. 'Volunteers consistently reported that the position of their hand had changed, even though it did not move.'

Source: How the mind senses movement. (2006) *New Scientist, 189(2537)*, 8 February.

QUESTIONS

1. What was the aim of this research?
2. What research method was employed?
3. What did the researchers conclude about the role of the motor cortex?
4. What ethical principles were important to observe in this research?

The parietal lobes

The parietal lobes are areas of the cerebral hemispheres located at the top of the cerebral cortex behind the frontal lobes, mostly associated with processing bodily (somatic) sensations.

Touch, temperature, pressure and other somatic sensations relating to muscle and joint movement and the body's position in space are registered in the parietal lobe's primary somatosensory cortex. The primary somatosensory cortex is a strip of neurons located at the front of the parietal lobe, adjacent to the primary motor cortex. Sensations detected in the sensory receptors located throughout the body and the skin are registered and processed in the primary somatosensory cortex. As a result, we feel a sensation and form a perception of what it is and where it came from. Sensory information from the left side of the body travels, in the first instance, to the primary somatosensory cortex of the right hemisphere's parietal lobe. Sensory information from the right side of the body travels first to the somatosensory cortex of the left hemisphere's parietal lobe.

As with the motor cortex, we find that the 'map' of bodily sensations on the somatosensory cortex is distorted. The homunculus in Figure 2.12 shows that the cortex reflects the *sensitivity* of body areas rather than their size. Sensitivity is a measure of the number of sensory receptors found in that part of the body. For example, the lips are large in Figure 2.12 because of their great sensitivity, and the back and trunk, which are less sensitive, are much smaller. You will notice also that each body part is represented on the somatosensory cortex according to its position on the body (adjacent body parts are adjacent on the somatosensory cortex). As for the motor cortex, parts of the body are represented on the somatosensory cortex in the opposite order to their position on the body. For example, sensations from the face, mouth and lips register towards the bottom of the somatosensory cortex and sensations from the feet and legs register towards the top.

Does the parietal lobe have other roles? The parietal lobe has a large area of association cortex that receives and integrates information from other brain structures and areas such as information from our visual and auditory cortices. This function of the parietal lobe enables us to determine where objects are located in space and where our body is positioned in space. Therefore, the parietal lobe is also involved in the coordination of senses and movement.

People with parietal lobe damage may lose sensation in a body area, they may become clumsy in their movements, and they may have difficulties with spatial skills. They may confuse left and right, and may suffer from spatial neglect (see pages 63–5) where they do not recognise one side of their body as belonging to them.

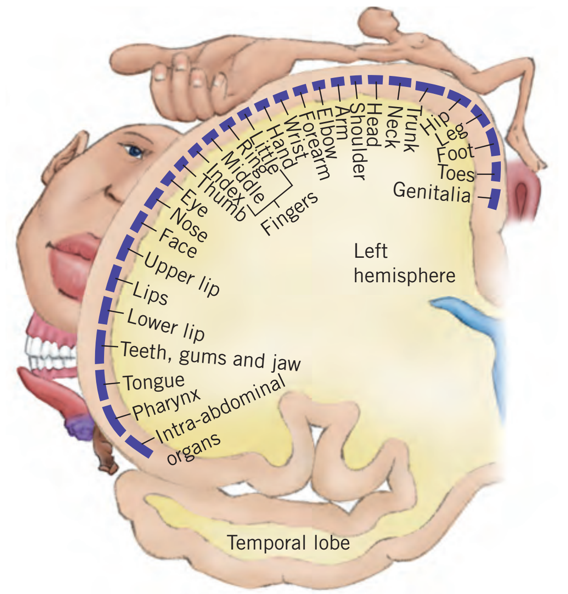


Figure 2.12 The somatosensory homunculus. Note the proportion of primary somatosensory cortex devoted to the hand, fingers, mouth and tongue.

The temporal lobes

The temporal lobes are located on each side of the brain. Auditory (sound-based) information received by both ears is transmitted directly to each temporal lobe, making them the main site where hearing registers. The temporal lobes contain large amounts of primary auditory cortex. The primary auditory cortex is the area of the temporal lobe that registers and processes auditory information. If we were to stimulate the auditory area of a temporal lobe, our subject would 'hear' a series of sound sensations. Additionally, different parts of the auditory cortex respond to a different pitch. The primary auditory

Broca's area
An area in the left frontal lobe close to the primary motor cortex that controls the muscles responsible for the production of articulate speech

parietal lobe
An area of each cerebral hemisphere located behind the frontal lobe; mostly associated with processing sensations but also involved in the coordination of senses and movement

primary somatosensory cortex
A strip of neurons located at the front of the parietal lobe, adjacent to the primary motor cortex, which registers and processes sensory information from receptors in the body

temporal lobe
An area located on either side of each cerebral hemisphere; associated with processing auditory information; also believed to be involved in memory, facial recognition, object identification and emotion

primary auditory cortex
The area of the temporal lobes that registers and processes auditory (sound) information

cortex in the right temporal lobe is specialised to process non-verbal sounds (for example, the sound of a siren or a door slamming), and the primary auditory cortex in the left temporal lobe is specialised to process verbal sounds that are associated with language.

For most people, the left temporal lobe also contains a second important language 'centre' known as Wernicke's area (identified by Carl Wernicke) (see Figure 2.9). (For five per cent of all people, this area is in the right temporal lobe.) Wernicke's area is located near the primary auditory cortex and it is connected to Broca's area by nerve fibres. Wernicke's area is the cortical area believed to be responsible for accessing words stored in memory; therefore, it is believed to be responsible for the comprehension of speech and the formulation of meaningful sentences (Gardner & Gardner, 1978).

The sounds associated with speech initially register in the primary auditory cortex of both hemispheres. However, the information must then be transferred to association areas in the left temporal lobe and processed by Wernicke's area if they are to be identified as words and their meaning understood. Because Wernicke's area is thought to be involved in locating words stored in memory, damage to the temporal lobe can severely limit the ability to understand and use language. People with damage to Wernicke's area can hear words or see them when written, but they do not understand their meaning. They can pronounce strings of words but their grammatical errors make their speech meaningless. Carl Wernicke's studies are described later in this chapter.

Does the temporal lobe have other roles? Psychologists believe the association areas of the temporal lobe contribute to memory (discussed in more detail in chapter 3), particularly our ability to recognise faces and identify objects, and make appropriate emotional responses. People who experience temporal lobe damage may be unable to remember previously-known facts or skills, may forget events that were personally significant and may demonstrate inappropriate emotional responses to people or situations. They may also be unable to recognise faces or objects even though they will still be able to describe them.

The occipital lobes

At the back of the brain we find the occipital lobes, the major visual area of the cortex. The occipital lobes contain large areas of primary visual cortex; an area at the base of the occipital lobe that registers and processes visual information transmitted from the retinas of both eyes. The optic nerves, which leave the back of the retina and connect with neurons in the primary visual cortex, provide the neural pathway along which this information travels.

When the retina in an eye receives an image, it is divided into a right visual field and a left visual field. Information from the right visual field of each eye is transmitted to the primary visual cortex in the left occipital lobe, and information from the left visual field of each eye goes to the primary visual cortex in the right occipital lobe. This arrangement ensures that information from both eyes goes to both cerebral hemispheres for processing.

The primary visual cortex contains a variety of neurons specialised to respond to specific features of visual information. For example, some feature detector cells contribute to vision by only responding to colour, some to shape and some to motion.

The specialised neurons in association areas of the occipital lobe select and integrate information from the primary visual cortex. In addition, they send visual information to other brain lobes. This helps the brain process a variety of different information at once, and form an integrated, meaningful understanding of it. For example, the association area might combine visual information about the shape, distance and speed of a ball being thrown at you with sound information from the auditory cortex – 'Catch!' – and input from the frontal lobe to help you judge whether you can catch the ball.

Does the information received by the primary visual cortex correspond directly to what is seen? Visual information arrives in many 'bits' that must be reassembled into a complete image by the visual cortex. The function of the visual cortex is partly to reassemble the 'bits' of information that arrive there into a 'whole picture'.

Damage to the occipital lobe may result in visual impairment even if the eyes and the optic nerve are uninjured. For example, individuals who experience a tumour in one of their occipital lobes may experience blind spots in their vision.

Association areas

Primary sensory and motor areas make up only a small part of the cerebral cortex. All the surrounding areas are called the *association areas*. They are found in every lobe of the brain and they are the brain areas where complex cognitive processes take place. The higher an animal is on the evolutionary scale, the more association cortex it has.

Association areas integrate information. They combine and process sensory information and link it with pre-existing ideas, concepts and memories. This role is crucial to our ability to recognise familiar objects, people and experiences. For example, if you see a rose, the primary visual cortex would register the shape, colour, size and texture of the rose; and the association cortex near the visual cortex would link that information with past knowledge of a rose (its name, the fact it has thorns, a mental comparison with other flowers). This kind of recognition seems automatic. When you recognise a familiar face or a piece of music, part of you knows you recognise the stimulus before your cortex has even had time to decide what it is. The conscious part of recognition takes place in the association areas of the cortex – here the face or music is given a name, an identity, a history, a context and a relationship to you so that it is understood (Hobson, 1999). The bulk of our daily experience and all of our understanding of the world can be traced to the sensory, motor and association areas of the cortex.

Complete 'Try it yourself 2.2' to gain a better understanding of the structures of the brain.

TRY IT YOURSELF 2.2
Make a brain model

Work in groups to make a model of the brain showing each of the four lobes. Each group will need:

- one quantity of playdough (see following recipe)
- four different food colourings
- 12 toothpicks
- light cardboard, A4
- scissors, glue and a stapler.

1 Make up the playdough according to the recipe.

2 Divide it into four equal quantities. Colour each amount with a few drops of different-coloured food dyes (red, blue, yellow and green are best).

3 Place the playdough in airtight containers.

4 Make up a number of small 'flags' to be used to identify various regions and structures of your brain model. Cut the card into strips of 6 × 2 cm. Fold them in half and write the following labels on one side of the flags:

- Frontal lobe
- Parietal lobe
- Temporal lobe
- Occipital lobe
- Motor cortex
- Somatosensory cortex
- Visual cortex
- Auditory cortex
- Association cortex
- Broca's area
- Wernicke's area

Form each card strip into a 'flag' by attaching it to a toothpick, using a stapler and glue or tape.

5 Make up your brain model, using the four different colours of playdough to indicate the four different lobes. Try to ensure your model is similar in size to an adult brain – about the size of a small cauliflower. You might also include the brain stem.

6 Label the features of the brain using your toothpick flags. Your teacher might award a prize for the most accurate representation – as long as you can explain the function of each of the key features!

Playdough recipe

1 cup flour

1 cup warm water

2 teaspoons cream of tartar

1 teaspoon oil

¼ cup salt

Mix all ingredients and place them in a saucepan. Stir over medium heat until smooth. Remove from pan and knead until blended and smooth. Allow to cool. The mixture will last for a long time if you place it in an airtight container or plastic bag.

CHECK YOUR UNDERSTANDING 2.3

1 Match each brain part with its relevant function.

a	Frontal lobe	i	Receives and process visual information
b	Parietal lobe	ii	Controls voluntary movement
c	Temporal lobe	iii	Receives sensory information
d	Occipital lobe	iv	Contains somatosensory cortex
e	Motor cortex	v	Involved with higher mental processes
f	Somatosensory cortex	vi	Contains visual cortex
g	Auditory cortex	vii	Combines and processes sensory information
h	Visual cortex	viii	Receives and processes auditory information
i	Association cortex	ix	Important in comprehension of language

2 The following patients have some sort of brain damage. Where is the damage likely to be? Choose the correct answer from the options given (i–iv).

a Patient A has difficulty interpreting what he is looking at.

b Patient B is having difficulty pronouncing words and speaking clearly.

c Patient C is having difficulty with memory.

d Patient D cannot register any sensation from his left hand and fingers.

i The left frontal lobe

ii The right somatosensory cortex

iii The left temporal lobe

iv The visual cortex

Continued

Wernicke's area
An area of the left temporal lobe responsible for the comprehension of language and the formulation of meaningful sentences

occipital lobe
An area located at the back of each cerebral hemisphere; associated with processing visual information

primary visual cortex
The area at the base of the occipital lobe that registers, processes and interprets visual information sent from each eye

3 What would a person experience if you stimulated each of the following areas of the brain? Choose the correct answer from the options given (i–iv).

a The left somatosensory cortex

b The top of the right motor cortex

c The temporal lobes

d The visual cortex

i Visual images

ii Sensation on the right side of the body

iii Movement of the elbow

iv Auditory or spiritual experiences

4 Why is the role of the association areas so important? (Choose the best response.)

A The association areas register and process all sensory information.

B They provide the link between all sensory areas of the brain, allowing information to be integrated.

C They represent the largest area of the cortex.

D They connect sensory areas with motor areas.

5 Indicate whether the following statements are true (T) or false (F).

a Broca's area in the left frontal lobe is involved in the production of articulate speech.

b The left hemisphere is where all major language functions are located.

c The comprehension of speech is a function of Wernicke's area in the right temporal lobe.

d Damage to Wernicke's area may result in incoherent speech.

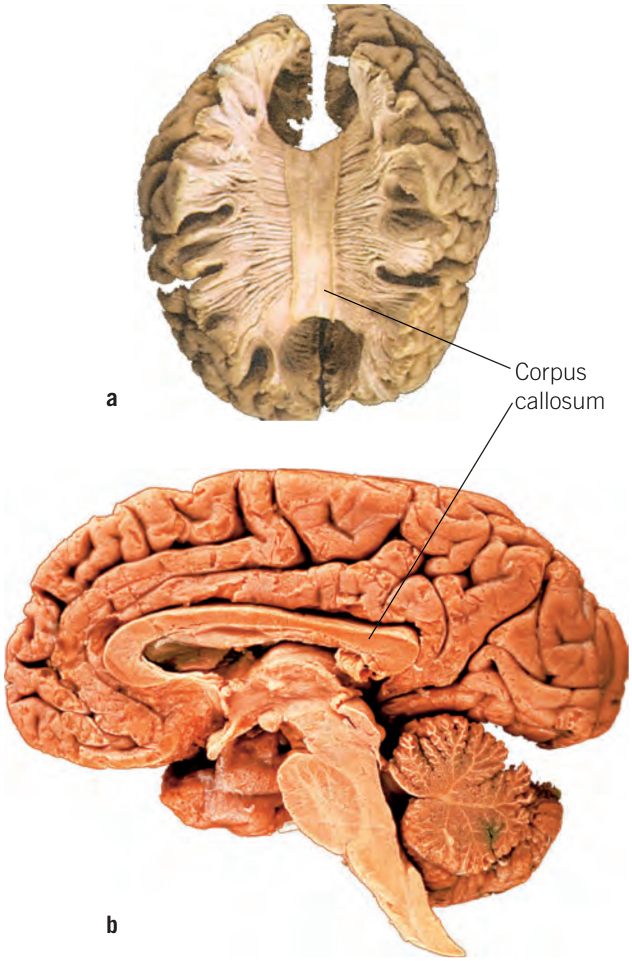


Figure 2.13 The corpus callosum connects the brain's left and right hemispheres. (a) The brain viewed from above with a section of each hemisphere cut out to expose the corpus callosum (b) a cross-section of the brain

THE CORPUS CALLOSUM

A superficial look at the outside of the brain reveals an obvious physical feature – the outer layer is made of two halves or hemispheres (the left hemisphere and the right hemisphere) – as mentioned earlier in this chapter. These hemispheres are separated by a deep groove – a longitudinal fissure – but connected by a thick band of nerve fibres known as the corpus callosum (see Figure 2.13).

Located deep in the centre of the brain, the corpus callosum is approximately 10 centimetres long and 7.5 mm thick. It is a major physical connection between the hemispheres and its job is to transfer information registered in one hemisphere to the opposite hemisphere for processing.

The role of the corpus callosum is important in everyday actions. For instance, if I were to place my right hand on a hot saucepan lid, the information about the heat of the saucepan lid would travel from my right hand to my brain's left hemisphere. The left hemisphere could relay a message back to the muscles in the right hand instructing them to pull the hand away from the hot lid. But, what if my left hand was holding the saucepan when my right hand touched the hot lid? I would also want to be able to balance the saucepan and place it down safely at the same time as retracting my right hand (see Figure 2.14). The information that had arrived in the left hemisphere would need to be transferred to the right hemisphere so that this hemisphere could relay a message to the left hand to place the saucepan down safely. Without the corpus callosum, this information could not be transferred between the two hemispheres.

Because the corpus callosum transfers information between hemispheres, it allows information from both hemispheres to be exchanged and integrated in a continuous way. Although we know that each hemisphere can perform specialised functions, most of our thoughts, feelings and behaviours involve both hemispheres working together.

Research into the effect of cutting the corpus callosum is investigated later in this chapter.

Figure 2.14 The corpus callosum is vital in integrating information from both hemispheres and coordinating actions.

THE CEREBRAL HEMISPHERES

The left hemisphere of the brain controls voluntary movement on the right side of the body. It also receives sensory information from the right side of the body. Likewise, the right hemisphere controls voluntary movement on the left side of the body and receives sensory information from the left side of the body. The differences in the roles of the left and right hemispheres of the brain can be illustrated when one side of the brain is injured or damaged. A stroke that causes damage to the right hemisphere can result in some paralysis and loss of sensation on the left side of the body. If a stroke occurs in the left hemisphere, the sufferer loses sensation in, and has difficulty moving, the right side of the body.

As we have already learnt, each cerebral hemisphere also has specialised primary sensory areas as well as association areas, and these are connected via the corpus callosum. But if each hemisphere has these specialised areas, why are they connected? Do they function separately or together?

The work of Paul Broca and Carl Wernicke in the 1800s identified the importance of each hemisphere for language functions. Other researchers have demonstrated that while the hemispheres work together in producing most of our behaviour, each has quite specialised functions.

To learn more about the cerebral hemispheres, view 'Videolink: Jill Bolte Taylor'. Taylor, a neuroanatomist, in this video explains the brain's hemispheres along with her own experience after suffering a stroke in 1996.

VIDEO
Jill Bolte Taylor

Left hemisphere: Verbal and analytical functions

The left hemisphere specialises in verbal and analytical functions. Roughly 95 per cent of people have their language centres (Broca's area and Wernicke's area) in the left hemisphere, so most adults use the left hemisphere for speaking, writing, reading and understanding language. In other words, for most of us, the ability to communicate our awareness using spoken or written language depends on left hemisphere function.

In general, the left hemisphere is mainly involved with *analysis* (breaking information into parts) and it processes information *sequentially* (in order, one item after the next) (Springer & Deutsch, 1998). It is superior at mathematics, judging time and rhythm and coordinating the order of complex movements, such as those needed for speech. The left hemisphere focuses on small details, so its focus is local (Heinze et al., 1998; Hellige, 1993; Huebner, 1998).

Right hemisphere: Non-verbal functions

The right hemisphere appears to process information *simultaneously* (at the same time) and *holistically* (all at once) (Springer & Deutsch, 1998). You could say that the right hemisphere is better at assembling pieces of the world into a coherent picture; it sees overall patterns and general connections and it has a global focus (Heinze et al., 1998; Hellige, 1993; Huebner, 1998).

Unlike the left hemisphere, for 95 per cent of adults the right hemisphere can produce only the simplest language and numbers. To answer questions, the right hemisphere must use non-verbal responses, such as pointing at objects or drawing them. However, although it is poor at producing language, it is superior at some aspects of *understanding* language. If this hemisphere is damaged, people lose their ability to understand jokes, irony, sarcasm, implications and other nuances of language. Basically, the right hemisphere helps us see the overall context in which something is said (Beeman & Chiarello, 1998).

The right hemisphere has specialised non-verbal perceptual skills. It is dominant in spatial skills and visual skills such as recognising patterns, faces and melodies, putting together a puzzle, reading a map or interpreting a painting. It is also more dominant in detecting and expressing emotion (Borod et al., 1998; Christianson et al., 1995).

Some tasks may make more use of one hemisphere over the other but, in most 'real-world' activities, the hemispheres share the work. Each hemisphere does the parts it does best, and shares information with the other hemisphere via the corpus callosum. Table 2.2 illustrates more clearly the specific functions of each hemisphere.

corpus callosum
A thick band of nerve fibres in the middle of the brain that connects the left and right hemispheres and transfers information registered in one hemisphere to the other hemisphere for processing

Try it yourself 2.3 includes an activity that draws on the contralateral organisation of the cerebral hemispheres – that is, the fact that the opposite side of the brain controls functions on either side of the body.

Table 2.2 Specialised functions of the left and right hemispheres

LEFT HEMISPHERE	RIGHT HEMISPHERE
Motor functions	
• Controls movement in the right side of the body • Production of speech	• Controls movement in the left side of the body
Sensory functions	
• Receives sensations from the right side of the body	• Receives sensations from the left side of the body
Perceptual functions	
• Comprehension of language	• Recognition of faces • Recognition of patterns
Cognitive functions	
• Reading • Writing • Analytical thinking • Sequential processing • Logical reasoning • Mathematics	• Musical ability • Spatial ability – design, movement, dance • Emotional expression • Detection of emotion

TRY IT YOURSELF 2.3
Hemispheric specialisation

Do each part of this activity twice, in pairs, swapping roles the second time.

Part 1

One person in the pair is to do the following:

- Stretch your arms out in front of you and then cross them, with the palms of your hands facing each other. Clasp your hands and interlock your fingers – your hands may feel upside down and back to front.
- Bring your arms down towards the floor and then move your clasped hands up towards your chest, bending your elbows. You may feel as if you're twisting your arms inside out. Your clasped hands should now be up near your chest or chin, and your elbows should be against your body.

The second person in the pair is to do the following:

- Point to one of your partner's fingers, but *don't touch them*. Ask them to move that finger. Repeat this with different fingers.

QUESTIONS

1. How long does it take you to move the correct finger?
2. How many errors did you make (moving the incorrect finger)?
3. How would you explain any difficulties you had?

Part 2

One person in the pair is to clasp their hands as explained in Part 1. The second person in the pair must now *touch* one of their partner's fingers, and ask them to move that finger. Repeat this with different fingers.

QUESTION

1. Is there any difference in the time it takes or in the level of difficulty?

Part 3

Repeat Part 1 of the activity but do not cross your arms before clasping your hands. Just clasp your hands in front of you as you would normally.

QUESTION

1. How would you explain the differences between the two conditions – crossed arms and uncrossed arms – in terms of the contralateral organisation of the motor and somatosensory cortices?

CHECK YOUR UNDERSTANDING 2.4

1 Copy and complete the following table of key functions of the two cerebral hemispheres.

	LEFT HEMISPHERE	RIGHT HEMISPHERE
Motor functions		
Sensory functions		
Perceptual functions		
Cognitive functions		

2 The corpus callosum:

A manages our understanding of speech and language.
B cannot process messages sent from the left hand.
C is a deep fissure in the cerebral cortex.
D is a thick band of nerve fibres linking the two hemispheres of the brain.

3 Indicate whether the following statements are true (T) or false (F).

a Generally the function of one hemisphere is more dominant than the other.
b The right hemisphere specialises in non-verbal functions while the left hemisphere specialises in verbal functions.
c Both hemispheres operate quite independently.
d We usually draw on both hemispheres to perform most functions.

4 State whether the following skills draw more on left hemisphere functions (LH) or right hemisphere functions (RH).

- a Writing with your right hand
- b Drawing a landscape
- c Reading a textbook
- d Rearranging the furniture in your bedroom
- e Doing a jigsaw puzzle
- f Reading a map
- g Working out an argument in a debate
- h Calculating your savings for a car
- i Playing a computer game
- j Listening to a song on your iPod

5 Joe is watching the tennis on TV. He loves tennis and he still plays, even though he had his corpus callosum severed several years ago. He has, however, lost the TV remote control and is feeling for it with his hands under the couch.

Which of the following actions could Joe *not* perform?

- A Feel the remote under the couch with his right hand and say 'Found it!'
- B Feel the remote under the couch with his left hand and say 'Found it!'
- C Understand the TV commentary on the tennis match
- D Follow the direction of the tennis ball with both eyes

THE RETICULAR ACTIVATING SYSTEM (RAS) AND THALAMUS

Two other important brain structures are involved in our ability to be awake and alert and to attend to stimuli in our internal and external environments.

Before incoming sensory information reaches the cerebral hemispheres, it must pass through the reticular activating system (RAS). The RAS is a network of neurons extending from the top of the spinal cord up to the thalamus. The thalamus is a structure that sits on top of the brainstem (hindbrain) and acts as a final 'switching station' for sensory messages on their way to specific cortical areas. Both structures act to modify our levels of arousal and alertness; they allow us to go to sleep and wake up, and enable us to attend to selected stimuli above others.

The RAS: Wakefulness and attention

Nerve fibres from sensory neurons have side branches into the RAS, which filter incoming sensory information, sorting it into 'important' and 'unimportant' categories. These side branches stimulate the RAS to send its own nerve impulses upward toward the cortex, arousing it to a state of alertness and activity. The RAS bombards the cortex with important sensory information. This stimulation keeps the cortex active and alert, which we experience as being in a state of conscious awareness. This is one of the most important functions of the RAS – to initiate and maintain a state of alert wakefulness.

Once alerted to the fact that new information is on its way, the brain is ready to process the sensory information. Unimportant information is ignored, and does not receive any further processing. This is selective attention, the second important function of the RAS. You learnt about attention in chapter 1 – selective attention refers to the ability to voluntarily redirect our attention to a specific stimulus while ignoring others.

When you are trying to cross a busy road without traffic lights, you need to be able to focus your attention on the cars passing in both directions, and judge the distance across the road and the time it might take for you to cross it. The activity of the RAS allows you to filter out the unwanted sensory information and concentrate on what is most important: getting across the road safely (see Figure 2.15).

Figure 2.15 Selective attention is vital in allowing us to focus on important stimuli and ignore others, such as when we need to cross a busy road.

reticular activating system (RAS)
A network of neurons extending from the top of the spinal cord up to the thalamus; filters incoming sensory stimuli and redirects them to the cerebral cortex, activating the cortex and influencing our state of physiological arousal and alertness

thalamus
A structure that sits on top of the brainstem (hindbrain) through which all sensory information, except smell, passes; re-directs this information to the appropriate sensory area of the cerebral cortex for processing

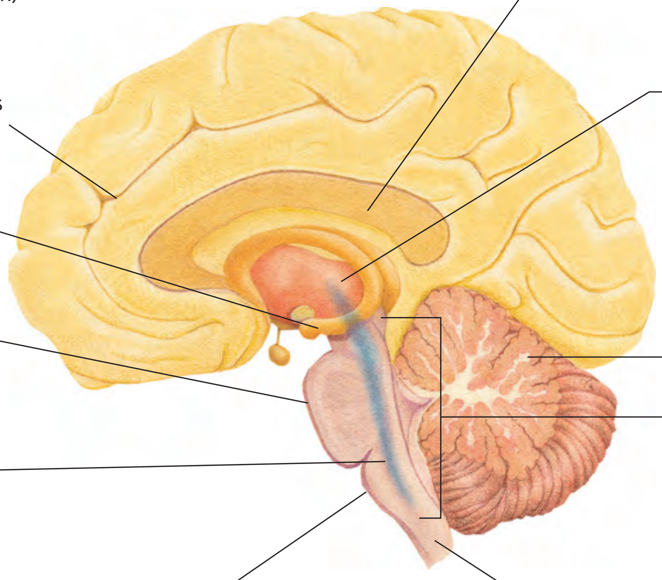


Figure 2.16 This diagram shows the reticular activating system (RAS) extending from the top of the spinal cord to the thalamus on top of the brain stem.

The RAS is not only involved in keeping us alert when we are awake – it is also involved in the control of sleeping and waking, and is often referred to as the brain's arousal centre. Experiments in which researchers have removed the RAS from animals have found that without the RAS they cannot be awakened, due to lack of arousal. If the RAS is electrically stimulated in sleeping animals, they will awaken immediately (Rosenzweig & Lieman, 1982). If you are ever sleepy reading this book or in your psychology class, try pinching yourself gently – a little sensory stimulation in the form of pain will cause the RAS to momentarily arouse your cortex.

The thalamus: The sensory switching station

The thalamus is a structure that sits on top of the brainstem (hindbrain) and acts as a kind of sensory relay station. Information from all senses, except smell, pass through this small football-shaped structure. (Smell links directly to the cortex – it bypasses the thalamus.) Each area in the thalamus is connected to a particular section of the brain's cortex, so the thalamus analyses the sensory information and directs it to the appropriate sensory areas of the cerebral cortex. For example, visual information from the eyes enters from nerve fibres connecting to the bottom of the thalamus. It is relayed to the primary visual cortex in the occipital lobe from nerve fibres that exit at the top of the thalamus.

However, this flow of information is not only one-way. There is a constant reciprocal flow of information between the thalamus and these different cortical areas of the brain. These connections are rapid and intense, and they are responsible for our ability to perceive the world with clarity and accuracy. That is why damage to the thalamus can cause deafness, blindness or loss of any other sense except smell.

When you experience a thunderstorm (Figure 2.17), information about the sound of the thunder, the pounding of the rain, the dark light from the clouds, the flash of lightning, the moisture in the air are all relayed to the thalamus, then to the area of the cortex responsible for registering all those different sensations, then back to the thalamus. This communication is so rapid that the numerous sensory inputs from the storm are noted, received, registered, processed and integrated all at once to provide a perception of the intense experience that is a thunderstorm.

Figure 2.17 A thunderstorm: Sensory information of most kinds is rapidly communicated to different areas of the cortex and back via the thalamus, to create this intense sensory experience.

The constant flow of information between the thalamus and cortex, known as a thalamocortical circuit, is thought to help to direct attention and coordinate complex tasks. Motor messages from the cortex also pass back through the thalamus to structures in the hindbrain and are involved in complex limb movements.

The thalamus is also viewed as a sensory 'on–off switch'. There are two functions that lead to this conclusion. First, the activity of the thalamus is regulated to some extent by the activity of the RAS. However, the thalamus is capable of modulating itself, so it can attend to some sensory inputs over and above others and switch attention on and off. This attention function is determined by the level of activity in the rest of the nervous system. When the activation level of the brainstem (hindbrain) is lowered, the connections between the thalamus and the cortex also begin to change rhythm. This drop in activation across these structures contributes to the loss of consciousness we see in sleep, particularly NREM sleep.

Second, the thalamus sends two kinds of messages to the cortex – some are excitatory (they encourage activity in the cortex) and some are inhibitory (they inhibit or prevent cortical activity). If the inhibitory messages outweigh the excitatory messages, the cortex does not respond to some sensory input. In this way, the thalamus acts to switch on or off some sensory input.

Researchers are coming to view the thalamus as a very important structure in three ways: it ensures that sensory input reaches the cortex; it helps direct attention to important stimuli; it plays a part in regulating the various levels and states of consciousness.

CHECK YOUR UNDERSTANDING 2.5

1 Create a table with two columns, headed 'Reticular activating system' and 'Thalamus'. Place the following statements in the correct columns of your table.
- Network of neurons from the top of the spinal cord into the forebrain
- Structure on top of the brainstem
- Final switching station for sensory messages
- Connects sensory messages to parts of the cortex
- Filters incoming sensory information
- Involved in selective attention
- Involved in wakefulness and arousal

2 Explain how the thalamus is involved in our going to sleep by filling the gaps in this sentence with the words provided.
- sensory
- switching station
- cortex
- on–off switch

The thalamus acts as a ___________ for all ___________ messages. It conveys information from the brain stem to the ____________________. It also acts as a sensory ______________.

3 Which of the following are examples of selective attention?
- A Focusing on the teacher in class and ignoring your friend talking to you
- B Listening to your friend talking while you take notes in class
- C Looking through the DVDs at the video store to see what might interest you
- D Scanning the CDs in your collection to find the one you got for Christmas
- E As you drive, moving your attention from the traffic flow to the light turning red at an intersection

4 Indicate whether the following statements are true (T) or false (F).
- a The RAS selects, sorts and directs incoming sensory stimuli to the cerebral cortex.
- b Damage to the RAS could result in loss of any of our senses except smell.
- c The thalamus directs the correct sensory information to the correct part of the cerebral cortex.
- d The RAS is also known as the brain's arousal centre.
- e Damage to the RAS can result in difficulties with sleeping or waking.

5 Place these steps of the journey of a sensory impulse into their most likely order.
- a Sensory information detected by sensory receptors
- b Cortex processes sensory information and relays back to thalamus
- c Sensory impulses reach RAS

d RAS filters most important information for further processing

e Thalamus analyses sensory information

f Sensory impulses are transmitted by sensory neurons along PNS to spinal cord

g Filtered sensory information reaches thalamus

h Thalamus swiftly relays sensory information to appropriate part of the cortex

Research into cognitive processes

While humans have been interested in the relationship between the brain and behaviour for centuries, it is only in the last 100 years or so that solid research has been able to provide a scientific basis for our understanding. Early case studies of individuals with impairments to particular cognitive functions provided useful information about the relationship between impairment and parts of the brain. Unfortunately, this was usually only possible after a patient had died and the brain was autopsied. Recent neuro-imaging techniques have, however, allowed neuroscientists to study the living brain in non-invasive ways.

BROCA'S APHASIA AND WERNICKE'S APHASIA

When brain damage through disease or injury results in language loss or impaired language ability, the person is said to have suffered an aphasia. Aphasia can be caused by damage to any one of several cortical areas involved in language. Some aphasia sufferers can speak fluently but they cannot read; others may understand what they read but cannot speak; some can write but not read; some can read but not write; some can read numbers but not letters; and others can sing but not speak.

In the late 1800s, French physician Paul Broca (Figure 2.18) studied patients with damage to the lower left frontal lobe, close to the motor cortex. This area later became known as Broca's area. He discovered that while patients with damage to this area could understand what was said to them and knew what they wanted to say in response, they simply could not *say* it. They may have been able to move their tongue and lips, but they had no ability to articulate all or some of the words required. Broca called this condition Broca's aphasia.

A typical patient with Broca's aphasia speaks slowly and laboriously, and uses simple sentences. Usually only the concrete words are pronounced and the connecting words are omitted. They might say, for example, 'Boy went beach' instead of 'The boy went to the beach'. The 'sentence' makes sense in some ways, but it is not articulate (fluent) and is incomplete. Some patients with Broca's aphasia cannot speak at all. View 'Videolink: Broca's Aphasia' to see a patient with Broca's aphasia.

VIDEO
Broca's aphasia

Around the same time, German physician and psychiatrist Carl Wernicke (Figure 2.19) studied patients with a different language deficit – the inability to understand speech

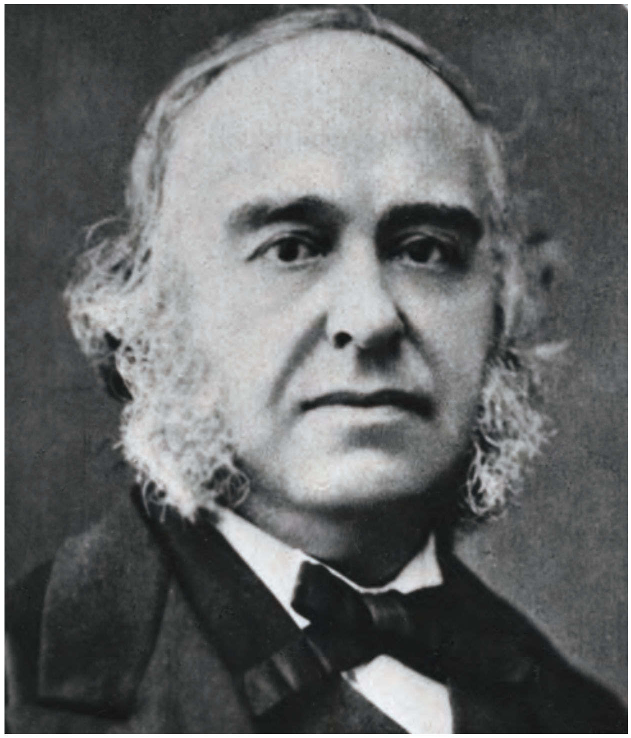


Figure 2.18 Paul Broca (1824–1880) identified the area in the left frontal lobe responsible for speech production.

Figure 2.19 Carl Wernicke (1848–1904) identified the area in the left temporal lobe involved in comprehension of language, later known as Wernicke's area.

or to produce coherent language. He identified a part of the brain in the left temporal lobe close to the primary auditory cortex as being the area responsible for language comprehension – Wernicke's area. The resultant language loss following damage to this area became known as Wernicke's aphasia.

Wernicke's aphasia refers to a difficulty with not only comprehending language but also producing coherent (understandable) speech. Unlike Broca's aphasia, where the difficulty is with the actual production of words, Wernicke's aphasia involves difficulty with the *meaning* of words. Speech may be perfectly fluent and sentences may even be grammatically correct; however, they do not make sense. Words are used inappropriately; sometimes even made-up words are used. Part of Wernicke's aphasia involves the inability to comprehend the speech of others as well as the inability to monitor one's own speech. So the patient may not even be aware that what they are saying does not make sense.

The Boston Diagnostic Aphasia Examination (BDAE) is a test often used to diagnose aphasia. One component of the BDAE requires patients to describe what is happening in a stimulus picture. When a patient with Wernicke's aphasia was asked to describe the illustration in Figure 2.20, the patient responded: 'Well, this is … Mother is always here working her work out of here to get her better, but when she's looking, the two boys looking in the other part. One their small tile into her time here. She's working another time because she's getting to. So two boys work together and one is sneaking around here making his work and further funnas (sic) his time he had.' (Carter, 1998)

View 'Videolink: Wernicke's Aphasia' to see a patient with Wernicke's aphasia.

VIDEO
Wernicke's aphasia

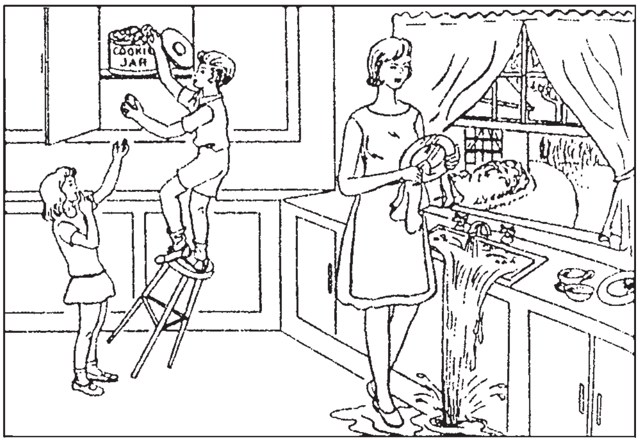


Figure 2.20 An illustration used in the Boston Diagnostic Aphasia Examination

While we know that Broca's area and Wernicke's area are crucial to speech production and understanding language, we also know that other areas of the brain are involved in language too. If you spoke to a person whose neural connection between their Wernicke's area and Broca's area is damaged, they would be unable to repeat what you said. Damage to the association areas surrounding either Broca's area or Wernicke's area would isolate them from the rest of the brain so the person would be unable to speak and may even appear to not understand what is said to them.

SPATIAL NEGLECT

Information about the roles of the cerebral hemispheres has also been provided by case studies of patients who have suffered hemispheric damage as a result of stroke or brain injury. A stroke occurs when the supply of blood to the brain is suddenly disrupted. This may occur because an artery to the brain is blocked by a blood clot or plaque, or because an artery breaks or bursts. For example, damage to the parietal lobe of either hemisphere can result in a condition known as spatial neglect – a tendency to ignore one side of one's body or one side of visual space after damage to one of the brain's hemispheres. Damage to the right parietal lobe is the most common cause of spatial neglect, which results in sufferers ignoring the left side of their visual space.

For spatial neglect sufferers, their damaged brain is unaware of some part of the outside world – in this case, one side of their body or one side of other objects. Often, sufferers of spatial neglect will not eat food on the left side of a plate and some even refuse to acknowledge a paralysed left arm as their own (Springer & Deutsch, 1998). If you point to the 'alien' arm, the patient is likely to say, 'That's not my arm. It must belong to someone else'. Studies of patients with spatial neglect have demonstrated the important role of the parietal lobe in receiving sensory information, the fact that each hemisphere receives information from the opposite side of the body, and the role of attention in our conscious awareness of the world around us. 'A closer look: Neglect – A partial view' examines the case of a patient with spatial neglect and 'A closer look: Spatial neglect not all in the mind' examines a study that sought to differentiate between spatial neglect and 'imaginary neglect'.

aphasia
A language impairment, usually caused by left hemisphere damage to Broca's area (impairing speech production) or Wernicke's area (impairing understanding of language)

Broca's aphasia
An impairment in the ability to produce articulate speech, caused by damage to Broca's area

Wernicke's aphasia
An impairment in the ability to understand language and formulate coherent, meaningful speech, caused by damage to Wernicke's area

spatial neglect
A tendency to ignore the left or right side of one's body or the left or right side of visual space resulting from damage to one of the cerebral hemispheres

A CLOSER LOOK

Neglect – A partial view

The patient had been left half-paralysed by a stroke, but seemed not to know it. This is a (condensed) conversation that took place between him and his doctor:

Doctor: Would you clap both your hands together, please?

[Patient lifts right hand and makes clapping motion in the air, then puts it back on bed. Smiles, apparently satisfied.]

Doctor: That was just your right hand. Could you raise your left hand and do it again with them both, please?

Patient: My left hand? Oh. It is a little stiff today. My arthritis.

Doctor: Could you try to lift it though, please?

[Pause. The patient does not move.]

Doctor [repeat]): Could you try to lift your left hand, please?

Patient: I did. Didn't you see it?

Doctor: I didn't. Do you think you moved it?

Patient: Of course I did. You can't have been looking.

Doctor: Would you lift it again for me, please?

[Patient does not move.]

Doctor: Are you moving it now?

Patient: Of course I am.

Doctor [indicating left hand lying on bed]: What is that then?

Patient [looking]: Oh, that. That is not my hand. It must belong to someone else.

The weird refusal to face facts shown by that patient is a well-recognised condition called anosognosia – a word meaning 'lack of knowledge of illness'. It is caused by damage to an area of the brain that is concerned with paying attention to one's own body. Anosognosia is fairly common among patients who have strokes that cause left-sided paralysis. This is because the area that is affected in anosognosia nestles very close to the motor cortex, and strokes (or other injuries) that affect the right motor cortex (therefore the left body side) often affect the area that is associated with anosognosia, too. Sometimes this peculiar dissociation from half of the body comes about when there is no paralysis. Patients just behave for all the world as though everything to one side of a vertical mid-body line has ceased to exist. They forget to move the limbs on that side. If they walk, they drag the neglected leg behind them. They do not comb one side of their hair. Sometimes – to the extent that it is practically possible – they even forget to put clothes on half their body. The condition is one form of an intriguing condition known as neglect.

Neglect may just be for the left half of the body or it may extend to involve everything in one half of the visual field. Again, the left side is usually the half that is blanked off.

Patients with this form of neglect do not appear to see or be aware of anything to their left. They leave food on the left side of their plate, ignore people who approach them from the left and turn only to the right. If they are asked to draw a clock, they will typically draw a vague right-handed hemisphere, with all the numbers crowded on to one side.

The one-sidedness usually continues even in the person's imagination. If they are asked to close their eyes and imagine walking down a familiar street they will describe, from memory, the buildings on the right but make no mention of those on the other side.

To all intents and purposes people with neglect are 'blind' to half the world. But this is no ordinary blindness. The parts of the brain that deal exclusively with visual input (the primary visual areas) are invariably intact and can be seen on scans to be processing incoming images in the normal way. The blindness is at a higher level in the brain – the level at which sensory input becomes a concept rather than just a stimulus.

People with neglect do not think: 'I cannot see to my left'. Their left simply does not exist in their minds as something to think about at all. Whereas a person with 'normal' half-hemisphere blindness would compensate by turning their head and body towards the blind side in order to bring it into sight, a person with neglect never feels the need to do this. When they read they tend to start each line from the middle of the page and continue to do this even when the text is plainly nonsensical as a result. It just does not occur to them that there is anything 'left-ward' to look at.

Neglect is best understood as a defect of attention – an inability of the brain to be conscious of some part of the outside world. What you are not conscious of you cannot miss.

Source: Carter, R. (1998) *Mapping the mind.* Orion, London, pp. 198–9.

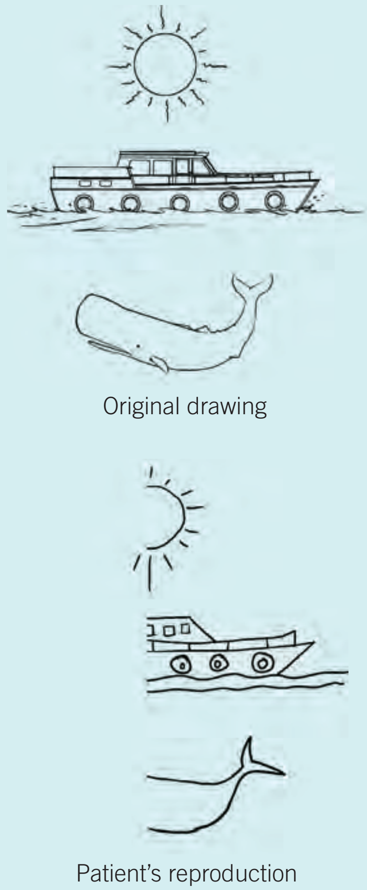


Figure 2.21 A patient with spatial neglect caused by damage to the right parietal lobe will reproduce the right half of a drawing only.

Spatial neglect not all in the mind

A CLOSER LOOK

An international research team has used lotto to show that the condition 'spatial neglect' is not connected to how it is imagined. Spatial neglect is a condition in which damage to either hemisphere of the brain results in patients being unable to perceive what is occurring on one side of their environment. The lack of perception is not due to blindness or visual obstruction, but an inability of the brain to read the signals it receives. Those with spatial neglect will consistently favour the unaffected side.

Lead researcher, Dr Tobias Loetscher of the University of Melbourne's School of Behavioural Sciences, says it is one of the most puzzling clinical symptoms of brain damage. 'I've seen patients who will only eat off the right side of the plate, they just leave the food on the left side and they are not aware that anything is wrong,' he says. 'They put make-up on the right side of the face and leave the left side alone.'

Loetscher and colleagues studied 37 Swiss stroke sufferers to determine whether 'imaginary neglect' co-exists with spatial neglect. To measure imaginary neglect, the researchers used a simulated game of lottery. Loetscher says previous research shows that when we imagine numbers we picture the smaller numbers to the left and the larger numbers to the right. By observing how the stroke patients selected lottery numbers on a physical ticket and comparing that to choices made using their imagination without a ticket to mark, it was possible to assess neglect in both the physical and mental worlds. In a large majority of cases (80%) the spatial neglect did not coincide with imaginary neglect.

Loetscher says that while the study is basic, it may have future implications for how particular stroke patients receive therapy. 'You could argue that somebody who has no neglect in their imagination might be able to shift their attention to the left side as part of their treatment, compensating a little bit,' he says. 'But if you also have neglect in the imagination, this might be much harder to do, because you are not able to envisage it in your imagination.'

Source: McGilvray, A. (2009) 'Spatial neglect not all in the mind.' *ABC Science online*. 18 August.

SPLIT BRAIN STUDIES: DEMONSTRATING HEMISPHERIC SPECIALISATION

Much of our knowledge about the specialised functions of the cerebral hemispheres comes from groundbreaking work of neuropsychologists Roger Sperry (1914–94) and Michael Gazzaniga (1939–) (see Figure 2.22). In 1981, Roger Sperry won a Nobel Prize for his work on the special abilities of the cerebral hemispheres, which demonstrated that both cerebral hemispheres perform differently on tests of language, reasoning, perception, music and other capabilities.

Previously we noted that Broca and Wernicke demonstrated that the left hemisphere specialised in language functions for most people. However, Sperry demonstrated that there was more to 'hemispheric specialisation' than simply language functions. He did this by testing the capabilities of each hemisphere separately.

How is it possible to test only one side of the brain? One way is to work with people who have had a split-brain operation. This is a rare type of

split-brain operation
Brain surgery involving the cutting of an area of the corpus callosum to interrupt the flow of information between the two cerebral hemispheres


a

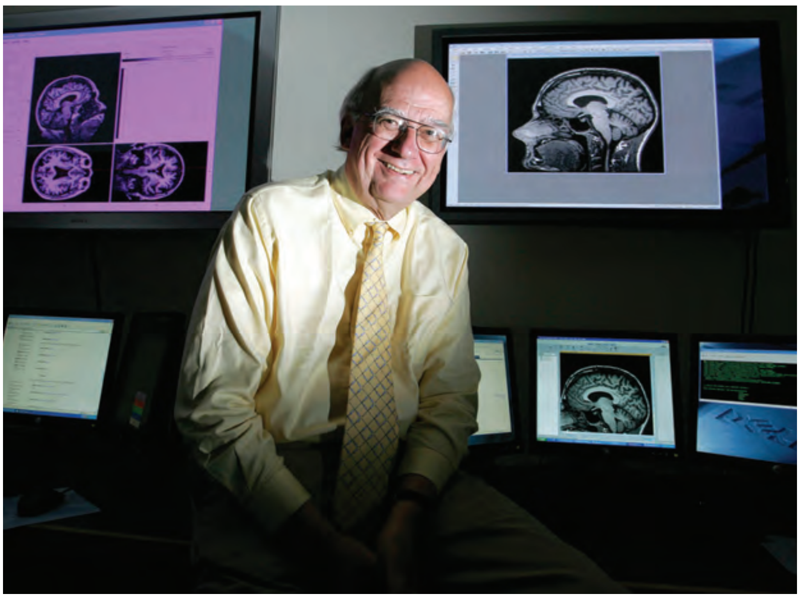

b

Figure 2.22 (a) Roger Sperry (1914-94) and (b) Michael Gazzaniga (1939-) pioneered split-brain surgery. Gazzaniga's research on consciousness continues today.

surgery in which an area of the corpus callosum is cut, usually to control severe epilepsy. After the surgery, it is a simple matter of directing information to one hemisphere or the other. Another less common method, called a WADA test, involves injecting a sedative into an artery, which sedates only one side of the brain.

Effects of having a 'split brain'

As noted earlier, the corpus callosum is the structure responsible for transferring information between the brain's hemispheres. Surgery that cuts the corpus callosum interrupts this exchange, so information registered in one hemisphere is unable to be transferred to the opposite hemisphere for processing. As a result, the brain cannot integrate information registered separately in each hemisphere. For example, as the 'speech centre' for most people is in the left hemisphere, information that enters the right hemisphere of the brain can only be verbalised if that information is transferred to the speech centre in the left hemisphere. For this transfer to happen, the corpus callosum must be intact.

Although we might imagine that someone with a 'split brain' might perform actions that continually conflict with each other, this is far from the truth. In fact, most split-brain patients' temperament, general intelligence and personality appear unaffected and they act completely normally.

Information usually travels at the same rate to each hemisphere, so both halves of the brain have the same experience at the same time. For instance, when you watch television, images enter both eyes at the same time and travel to each hemisphere at the same rate, arriving at the same time.

However, problems arise for a split-brain patient when a response requires information from one hemisphere to be integrated with information from the other hemisphere. For example, when you read this page, similar visual information is registered on the retina of each eye and travels to each hemisphere. Information from the right visual field (that is, from the right side of that person's vision) goes to the left hemisphere where the speech centre enables you to repeat this information (silently or aloud) to yourself. However, if you receive information *only* in your left visual field, the information taken in would travel *only* to your right hemisphere, and if you had a 'split brain', this information could not be transferred to and integrated with information in your left hemisphere's speech centre. As a result, you could not say in words what you have just seen on the page. Figure 2.23 demonstrates how information taken in by the left and right visual field is transferred to the opposite brain hemisphere.

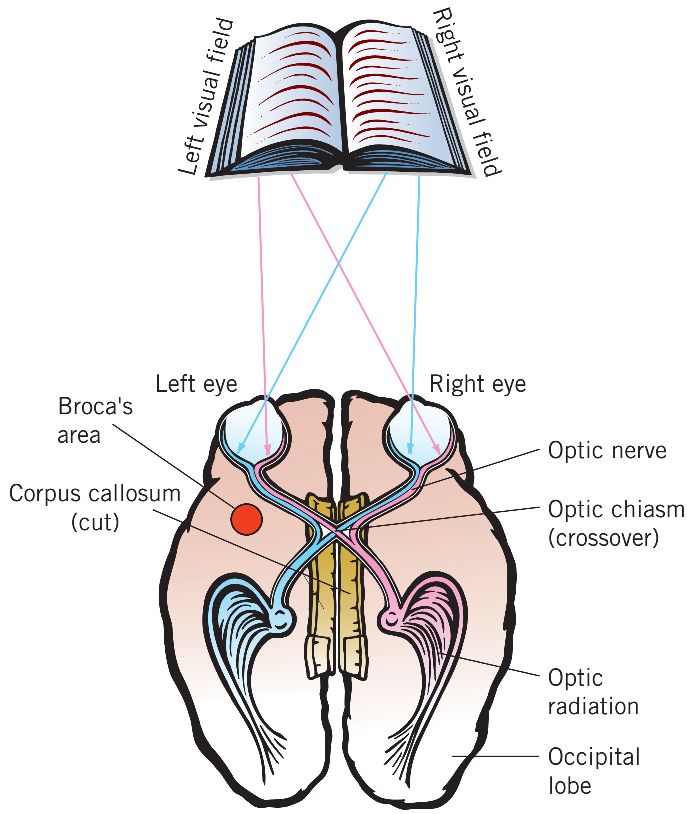


Figure 2.23 Visual information received in the left visual field is sent to the right hemisphere; visual information received in the right visual field is sent to the left hemisphere. A patient with a severed corpus callosum can say what has been read in the right visual field because this information travels to the visual cortex in the left hemisphere, where Broca's area is located. This patient would not, however, be able to say what has been read in the left visual field if they had not also read that information in their right visual field.

Sperry and Gazzaniga's research

In the 1950s, Roger Sperry conducted split brain operations at the California Institute of Technology and systematically observed the resulting behaviour of his patients. In 1968 he conducted a series of tests that involved presenting information to only one hemisphere of patients' brains.

In Sperry's experiments, participants sat at a table with a screen in front of them, on top of the table. Participants' hands could fit under the screen to reach objects on the other side, but they could not see the objects or their own hands. Participants fixed their sight on a point in the centre of the screen. A projector then flashed images onto the screen to either the participant's left or right visual field *only*. Information presented to only the left visual field was sent to the right hemisphere of the brain. Information presented to only the right visual field was sent to the left hemisphere. The experimental set-up is shown in Figure 2.24.

When patients were asked, 'What did you see?' the answer depended on which visual field the image had been presented to. As the information from the right visual field travelled directly to the left hemisphere (where the 'speech centre' is located),

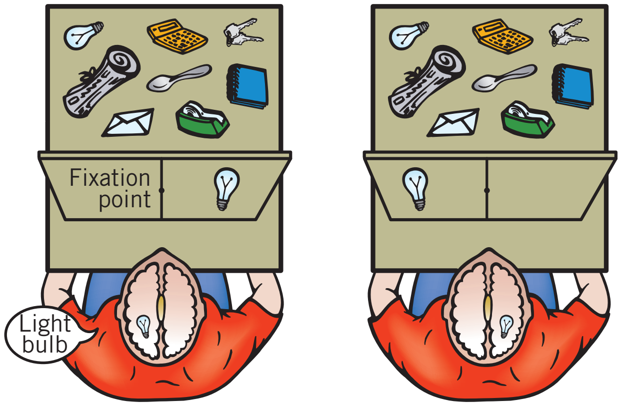


Figure 2.24 The experimental set-up for Sperry's experiments

the patient could say what they had seen. As the information from the left visual field travelled directly to the right hemisphere and could not be transferred to the left hemisphere, the patient could not say what had been seen. The two hemispheres could not communicate because the corpus callosum had been severed.

During many studies, Sperry found that while split-brain patients could not *say* the image they had seen in their left visual field, they could *demonstrate* the item by pointing to it, touching it or drawing it with their left hand. They could do so only with their left hand because the information about the item was 'trapped' in the right hemisphere, which controls movement on the left side of the body.

Sperry concluded that the corpus callosum was essential in allowing information to be exchanged between the hemispheres. Of particular importance was the transfer of visual information from the right hemisphere to the left hemisphere where speech processing takes place.

Sperry was a colleague and mentor to another noted neuropsychologist, Michael Gazzaniga, who has led pioneering research into an area he calls 'cognitive neuroscience'. Gazzaniga began his work with a split-brain patient known as 'W. J.' in 1962, and his experiments dramatically demonstrated left hemisphere specialisation in language functions in humans.

Sperry had demonstrated this in other animals but when Gazzaniga flashed items in W. J.'s left visual field and waited for the responses of his right hemisphere, W. J. responded to the stimulus by pressing a lever with his left hand as instructed, but claimed to not see any images at all. Gazzaniga concluded that W. J.'s right hemisphere was unable to process the information verbally, so he could not say what he had seen but he was able to acknowledge he had seen the images with an action performed by the left hand.

Gazzaniga's work confirmed the right hemisphere's superiority at performing visual and spatial tasks, such as drawing three-dimensional shapes, and the left hemisphere's specialisation for language, speech, and problem-solving.

VIDEO Severed corpus callosum

VIDEO Gazzaniga's research

View 'Videolink: Severed corpus callosum' and 'Videolink: Gazzaniga's research' to see case studies of patients who have had split-brain surgery. 'Focus on research: Split-brain research shines spotlight on left hemisphere strengths' examines another of Gazzaniga's studies.

FOCUS ON RESEARCH Split-brain research shines spotlight on left hemisphere strengths

A study conducted by Gazzaniga and his colleagues and published in the March 1995 issue of *Psychological Science* offers a peek at the contrasting approaches of the two hemispheres. Three split-brain patients and 10 people with no neurological problems attempted to identify unique elements in visual arrays presented to one side of the visual field. So-called standard search trials contained a black circle surrounded by clusters of gray circles and black squares, each about equal in number. Guided search trials presented a black circle with a few black squares and a much larger number of gray circles; this pattern enabled volunteers to hone in on the black circle by concentrating only on the small group of black items.

Split-brain patients and controls were adept at using either hemisphere to conduct standard searches. On guided search trials, the control group responded more quickly than they had on standard searches, though just as accurately, regardless of which side of their brains the researchers recruited. But split-brain volunteers showed comparable improvement only when using their left hemispheres.

Results such as these indicate that the right hemisphere contains mechanisms for soaking up the raw material of sensory experience, Gazzaniga suggests, whereas the left hemisphere favours more complex sensory strategies.

Source: Adapted from Bower, B. (1996) Whole-brain interpreter: a cognitive neuroscientist seeks to make theoretical headway among split brains. *Science News*, 24 February.

QUESTIONS

1 What type of research was conducted by Gazzaniga?
2 What was the purpose of the control group?
3 List the results of the research.
4 What could Gazzaniga conclude?

CHECK YOUR UNDERSTANDING 2.6

1 Copy the following table into your workbook and insert 'Yes', 'No' or 'Sometimes' into the appropriate spaces.

	BROCA'S APHASIA	WERNICKE'S APHASIA
Can speech be produced?		
Is speech articulate (fluent)?		
Is speech coherent?		
Can others' speech be understood?		
Can own speech be monitored and understood?		

2 Which part (hemisphere and lobe) of the brain is damaged in these examples of spatial neglect?

a A patient eats food from only the right side of their plate

b A patient shaves only the left side of his face

c A patient reads only the left side of a menu in a restaurant

d A patient puts makeup on the right side of her face only

3 If the patient in 2 (d) has her attention drawn to the fact that she has only put makeup on the right side of the face, she is likely to:

A deny it.

B put makeup on the left side.

C be embarrassed.

D notice the absence of makeup.

4 Match the sentence halves.

a Split brain surgery is usually conducted	i the ability to perform most functions.
b Following split brain surgery,	ii to control severe epilepsy.
c Split brain surgery does not affect	iii patients have difficulty integrating information between the hemispheres.

5 A split-brain patient, Jack, is placed in front of a screen where images are flashed to only one visual field – the left or the right. Identify whether these statements are true (T) or false (F).

a Jack could draw an image of a cat flashed to the left visual field with left hand only.

b Jack could state what has been seen when the cat image is flashed to his left visual field.

c Jack could state what he feels with his right hand when he handles a toy car behind the screen.

d Jack could draw what he feels in his left hand when he is handed a pen behind the screen.

PERCEPTUAL ANOMALIES: DISTORTING CONSCIOUS AWARENESS

Sperry and Gazzaniga demonstrated that while each hemisphere has specialised functions, generally they work together to enable us to receive information from the world, process it and respond to it. In most cases our brain structures and cognitive processes work together to produce a realistic perception of the world. In other words, our conscious awareness of our environment is supported by the reality of this environment.

But what happens when these processes do not function as we expect? How can we explain unusual experiences in receiving, processing and responding to sensory input? In other words – what happens when we experience a perceptual anomaly (a deviation from the way we normally process and perceive information)?

Motion after-effect: The Waterfall illusion

Have you ever had the experience of watching a moving scene, such as a waterfall (Figure 2.25), and then perceived a static object you looked at afterwards as moving – in the opposite direction?

Figure 2.25 The Waterfall illusion is an example of motion after-effect.

This particular phenomenon is often called the *Waterfall illusion*; however, in psychological terms it is known as the motion after-effect.

One explanation for the motion after-effect is that the neurons in the visual cortex that fire in response to the motion become fatigued over time. When you stare at a moving object, these cells signal movement in one particular direction. When you shift your attention to something else, these neurons fail to fire. However, as neurons that signal movement in the opposite direction are now generally more active than those that are fatigued, your brain interprets that as movement in the opposite direction. To experience the motion after-effect, try staring at the moving wheel of a car or a bicycle for a few seconds. If you look away for a few seconds and look at another, non-moving, wheel, it will appear to be turning in the opposite direction.

But why don't we experience motion after-effect after a long car trip where we were looking out the window at the landscape whizzing past? One explanation suggests that when you are sitting in a car, the whole of your visual field is moving. This is unlike viewing a waterfall or spinning wheel, where the motion is off-set by a stationary background.

Motion after-effect studies demonstrate that even though our brain has highly specialised neurons that respond to input such as motion, it also has limitations when that input is continuous or unchanging. View 'Videolink: Motion after-effect' to experience motion after-effect.

VIDEO
Motion after-effect

Change blindness and inattentional blindness

A popular joke on TV sitcoms in past and present eras is the gender-stereotyping situation where a woman comes home wearing a new haircut or new outfit, and her husband does not notice. The woman then tries more extreme changes to her appearance in an effort to be noticed (see Figure 2.26). This is known as change blindness – a form of perceptual blindness that occurs when we fail to notice large changes in a visual scene. This failure to notice is usually because the changes occur at the same time as a disruption to our vision and, in particular, a disruption to our attention.

This disruption most commonly involves moving the eyes. For example, you may be watching a cricket match where one batsman is on a long innings. You may then reach down to pick up a sandwich, looking down as you do so, and when you re-focus on the cricket match you may fail to notice that the batsmen have changed ends. If you travel a familiar route to school each day, it may take you several days before you notice that a large tree has been removed, or a house painted a different colour or a shop changed hands.

In order to detect a change, we must be able to have two visual images held in our memory so we can compare them. If the change occurs in an object that is not important to us, it is likely we have not stored its image in our memory, or we have only stored part of it, so a comparison is not easily made. We may be aware that a change has occurred but cannot identify exactly what it is.

Change blindness can be a serious limitation. For example, when driving long distances, any interruption to our visual attention may mean we fail to notice changed driving conditions, which could have serious consequences. This is just as serious a problem for a VCE student when proofreading a piece of writing – how often have you missed the most obvious errors?

Change blindness illustrates the importance of attention in cognitive processes and the important roles of the RAS and thalamus as a sensory filter. View 'Videolink: Change blindness' to learn more about change blindness.

VIDEO
Change blindness

Closely related to change blindness is the concept of inattentional blindness, which is the failure to notice an unexpected object that is fully visible in the environment because attention was

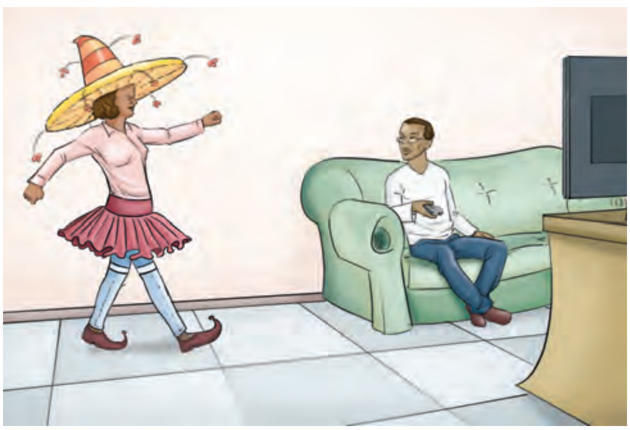


Figure 2.26 Change blindness occurs when we fail to notice large changes in a visual scene due to disruption to our attention.

perceptual anomaly
A perceptual irregularity due to deviation from the normal mental processes used to give meaning to stimuli

motion after-effect
A perceptual anomaly experienced after viewing a moving object for a period of time and then viewing a static object – which then appears to move in the opposite direction to the original moving stimulus

change blindness
A perceptual anomaly or form of perceptual blindness involving a failure to notice large changes in a visual scene

inattentional blindness
A perceptual anomaly involving the failure to notice an object that is fully visible in the environment, because attention was not focused on it

not focused on it. One famous demonstration of this was carried out by Dan Simons and Chris Chabris in 1999. (The Videolink on focused attention that you saw in chapter 1 involved a variation on this experiment. Revisit this to refresh your memory.) An audience was shown a video of a group of young people passing a basketball to each other. Before viewing the film, the audience was instructed to count the number of passes and report back at the end of the film. In the film, as the ball was being passed, a person dressed in a gorilla suit walked into the middle of the scene, waved at the camera and walked off. When the audience reported back at the end of the film, approximately half of them did not report having seen the gorilla.

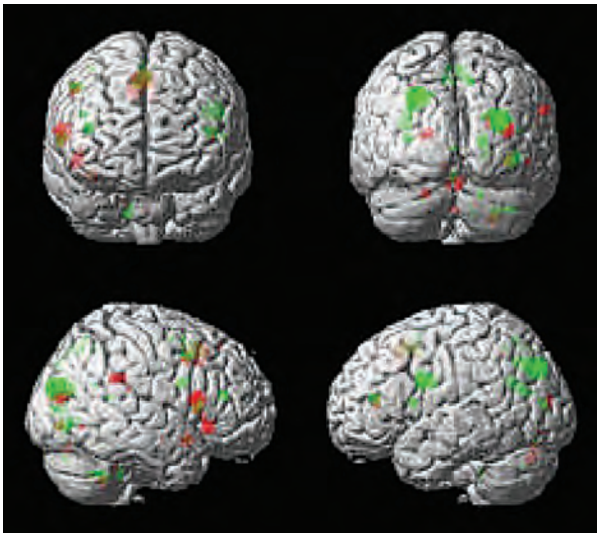
It would seem that those people were distracted by the counting task and therefore failed to attend to the gorilla. Even when prompted, those participants said they did not recall seeing the gorilla. However, we know that they must have seen the gorilla – the image was there, so it *must* have reached the retina in the back of their eyes and travelled to the brain's visual cortex.

Synaesthesia: Can I see what I hear?

Some people experience a form of sensory 'crossover' known as synaesthesia, where information taken in by one sense is experienced in a way normally associated with another sense. Sounds, for example, can be experienced as tastes or colours; tastes and smells can be experienced as sounds or associated with visual input.

Synaesthesia is an involuntary condition and is usually present from birth. Despite considerable research, there is no clear explanation for why synaesthesia occurs. As the condition is more common in childhood, one theory suggests that it is the result of the brain's failure to remove excess neurons in adulthood. Another popular explanation is that synaesthetes (people who have synaesthesia) have additional neural connections that cross over from one area of cerebral cortex to another. This explanation is disputed by some researchers who claim it does not explain the fact that synaesthesia can occur when under the influence of some drugs or during epileptic seizures. They suggest it is more likely that the association cortex is involved (Greenfield, 2001).

Recent studies of synaesthesia have provided valuable insights into the ways in which the specialised regions of the brain do function to provide us with interpretations of the world around us. Figure 2.27 illustrates how an fMRI (see later in this chapter) can demonstrate the activation levels of different parts of the brain in synaesthetes. 'A closer look: Some sound red while others just taste green' describes the experience of a synaesthete. 'Focus on research: Do we all have the capacity for synaesthesia?' explains some research into the condition.

a


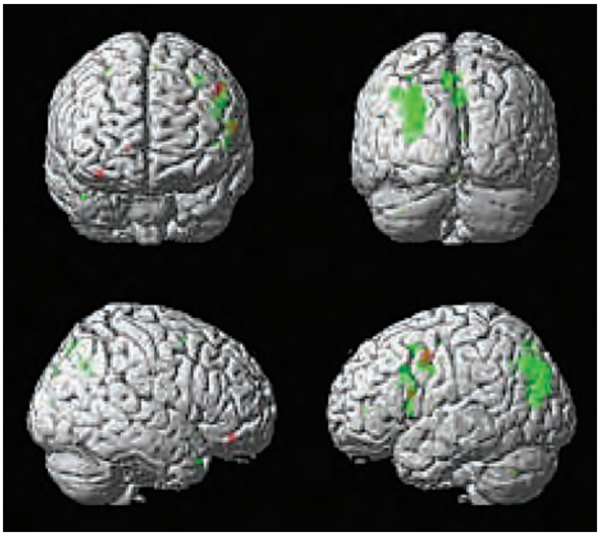
b


Figure 2.27 These fMRI images illustrate how reading words activates many more brain areas for synaesthetes (a) than for controls subjects (b) (Coloured areas denote activation.)

A CLOSER LOOK

Some sound red while others just taste green

Cameron has a friend whose voice tastes like graham cracker crust with cinnamon and butter. Another friend's voice tastes like metal and sharp cheddar. Cameron has synaesthesia, the unusual mixing or mingling of the senses.

Synaesthesia is quite rare; only one adult in 2000 has it, according to the only reliable published estimate. However, it might turn out to be more common than this; many people with synaesthesia, myself included, were surprised to discover it was anything unusual.

A review of the latest research into synaesthesia was published in *Nature* early in 2002. The most common form of synaesthesia is when specific digits, letters or words trigger colours.

The colour of the first letter of a word is usually the most important, but other letters can also influence the overall colour of a word. For example, the word 'synaesthesia' is red for me because of all the Ss (the letter S is always red in the mind's eye) with a hint of dark green from the letter N.

More women than men have synaesthesia but the exact proportion and possible reasons are still hotly debated. Researchers at the University of Cambridge have also discovered that synaesthesia runs in families, which strongly suggests it has a genetic basis.

I experience synaesthetic colours in my mind's eye but a minority of synaesthetes actually see these colours overlaid on their field of vision.

Each synaesthete has a unique set of connections (between letters and colours, for example), which is stable long-term. Some letters and digits have very strong colour associations for me (3 is bright pink), some are more subtle (P has an essence of blueness), and others are a murky non-colour, like D. However, colours don't trigger numbers or letters.

I've experienced a harpsichord piece by Bach as orange and spiky, and a recording of a blue wren's call as silvery oval shapes. Another time I had an orange backache with random bright sparkly blue stabs of pain.

As well as coloured music, sounds and pain, synaesthesia can result in the mingling of any combination of the senses: tasting voices, feeling sounds or hearing colours. It can be a great memory aid for things like phone numbers because it's all colour-coded. One American researcher, Richard Cytowic, calls this type of recall 'mental gymnastics', but it's natural for synaesthetes to remember the colour of something first and then its name.

Many synaesthetes quite enjoy their quirky minds. It's like having an extra sense that they would miss if it was gone. However, a few people who have more intense and varied forms of synaesthesia (like Cameron) can sometimes feel overwhelmed.

Researchers across the world started studying synaesthesia several decades ago. There are two types of experiments currently being used to study this condition. One is imaging of synaesthetes' brains using techniques such as MRI to find out which parts are more active than in people without the syndrome.

The other compares how well synaesthetes and non-synaesthetes do on carefully designed visual tests. One such test devised by researchers in Melbourne showed synaesthetes coloured letters or numbers. If the colour matched their synaesthetic colour, they were faster at naming the real colour, but slower at naming if the colour was different.

One theory is that synaesthesia is caused by permanent cross-wiring between areas of the brain that deal with different senses. The idea is that we're all born with extra connections between the senses that then get pruned during childhood, but for some reason this pruning partially fails in the brains of synaesthetes.

Other researchers think that the wiring in synaesthetes' brains is normal but that information from one sense can leak into the wires for another sense because of feedback problems in the wires. The most controversial theory says that synaesthesia occurs in a completely different part of the brain; the limbic system, which controls emotions and memory.

Source: Hatch, S. (2002) 'Some sound red while others just taste green.' *Canberra Times*. November.

FOCUS ON RESEARCH

Do we all have the capacity for synaesthesia?

Do we all have the capacity for synaesthesia or is the brain's ability to blend senses bestowed on a select few at birth? It now seems it could be a mixture of the two.

Synaesthesia seems to underpin some savants' enhanced memory and numerical skills. The hope is that a better understanding of its origins could help to explain savant abilities – and perhaps even shine some light on whether we are all capable of attaining them.

The condition is thought to arise when extra connections in the brain cross between regions responsible for separate senses. To see if genes play a role in building or maintaining these connections, a team led by Julian Asher at the University of Oxford took genetic samples from 196 individuals from 43 families, 121 of whom exhibited auditory-visual synaesthesia, meaning they 'see' sounds. 'When I hear a violin, I see something like a rich red wine,' says Asher, who is a synaesthete. 'A cello is more like honey.'

From their analysis, the team was able to pin down four chromosomal regions where gene variations seemed to be linked to the condition. As one of the regions has also been associated with autism, there may be a common genetic mechanism underlying the two, says Asher.

So if we are genetically disposed to develop synaesthesia, does that rule out the possibility of inducing the experience? To find out, Roi Cohen Kadosh from Imperial College London and colleagues hypnotised four volunteers so that they viewed numbers as having innate colours, known as grapheme-colour synaesthesia. The volunteers then looked at a series of coloured slides, some with a black digit in the centre and some without.

Like people with synaesthesia, roughly 80 per cent of the time the hypnotised volunteers failed to see the digits when the background colour corresponded to the colour they associated with a number. Controls who had not been placed under a trance, but were instructed to attach a colour to each number, did not make this mistake.

'It shows that even without hyperconnectivity in the brain, you can still have synaesthesia,' says Cohen Kadosh. He says hypnosis may reactivate connections that had been suppressed by the brain.

Julia Simner from the University of Edinburgh, UK, has further evidence that synaesthesia is not the result of neural connections fixed before birth. She studied 615 6–7 year-olds, eight of whom turned out to be grapheme-colour synaesthetes. Over the course of a year, these children gradually associated more letters with colours, showing that the ability developed with time.

So should we all attempt to develop savant-like abilities? 'Synaesthesia is strongly linked to improved memory capabilities so it would definitely be a good thing to research,' says Simner. Asher is more cautious, stressing that synaesthesia is often distracting, for example, while reading or listening to a lecture. He hopes to develop a genetic test to diagnose children and warn teachers of potential difficulties.

Source: Robson, D. (2009) Do we all have the capacity for synaesthesia? *New Scientist*, 201(2695), p. 13.

Continued

synaesthesia
A perceptual anomaly where information taken in by one sense is experienced in a way normally associated with another sense

QUESTIONS

1 What was the aim of the second research by Kadosh?
2 Suggest an operational hypothesis Kadosh might use.
3 What was the purpose of the control group?
4 Describe the results in one sentence.
5 What could Kadosh conclude about synaesthesia?

CHECK YOUR UNDERSTANDING 2.7

1 Which is the best definition of a perceptual anomaly?
   A A visual illusion
   B A perceptual hallucination caused by a deviation from normal mental processes that give meaning to stimuli
   C A perceptual irregularity caused by a deviation from normal mental processes that give meaning to stimuli
   D A perceptual confusion caused by sensory overload

2 Choose the appropriate words from those provided to complete the explanation of how the Waterfall illusion demonstrates motion after-effect.
   - static
   - opposite
   - moving
   - upwards

   After viewing a _______ stimulus (such as a waterfall) for a period of time and then viewing a _______ stimulus (such as a cliff face), the static stimulus then appears to move in the ________ direction to the original moving stimulus. As the waterfall flows downwards, the cliff face may appear to move _________.

3 What limitation of our perceptual processes does motion after-effect demonstrate?
   A Neurons in the brain that are specialised to receive sensory input are limited when that input is continuous or unchanging
   B Neurons become fatigued over time
   C A failure of selective attention
   D None of the above

4 Which is the best example of change blindness?
   A You can't remember what colour shirt your best friend was wearing at the weekend
   B You don't notice that your teacher has had a haircut since yesterday
   C You realise that a noisy machine has stopped but don't remember it starting
   D You are absorbed in reading a book and don't notice that the room has gone dark

5 Choose the appropriate words to complete the paragraph about synaesthesia.
   - synaesthetes
   - crossover
   - disputed
   - taste
   - involuntary
   - association

   Synaesthesia is a(n) _________________ condition. The explanation for why it occurs is __________________. However, there is evidence that the _________________ cortex is involved. Synaesthesia is described as a kind of sensory ____________________, and ____________________ experience sensory information taken in by one sense in a way normally associated with another. For example, a sound may be associated with a ____________________.

Brain research methods

What we know about the brain has been the result of many different research methods over the centuries. Neuropsychology, or the study of how physiological processes relate to behaviour, began as a formal discipline in the 19th century. The most rapid advances have been made in the past 50 years.

CASE STUDIES

Many brain functions have been identified by case studies (see chapter 9 for more information about case studies). These in-depth studies examine changes in an individual's or group's behaviour, usually caused by brain diseases or injuries. In the late 19th century, as we saw earlier in this chapter, Paul Broca and Carl Wernicke discovered important structures in the brain that were responsible for language. They discovered these structures through studying cases of patients who had experienced damage to these parts of the brain and systematically observing the effects this damage had on their language abilities. More recently, Michael Gazzaniga, building on the work of Roger Sperry, has examined the effects of split-brain operations on individual patients and explored the capacity of each hemisphere to act independently of the other. This has led him to question some of our fundamental assumptions about human consciousness.

Case studies as a form of psychological research often involve brain-damaged subjects, but there are now ways to study a healthy brain and learn about the interaction between brain structures and cognitive processes.

BRAIN STIMULATION TECHNIQUES: ACTIVATING BRAIN AREAS

One commonly used technique for studying brain function involves electrical stimulation of various parts the brain and then noting the resulting behaviour. Electrical stimulation uses electrodes or magnetic pulses to deliver a weak electrical current to targeted brain areas or structures.

Direct brain stimulation

Direct brain stimulation involves using an electrode to deliver a measured electrical current to the brain by placing it directly onto a brain area or inserting it into a brain structure. An electrode is a tiny, thin metal probe that delivers a carefully measured electrical current. We know that neurons transmit information by generating small electrical currents, so by touching an area of the cortex's surface with an electrode or inserting it into a structure, targeted neuron groups can be stimulated and their electrical activity measured.

Wilder Penfield (1891–1976) pioneered this technique in the 1950s. While treating patients with epilepsy and trying to identify the cause of their seizures, he discovered that by stimulating different parts of the brain's cortex (on patients who were awake and could respond), he could demonstrate which parts of the cortex were involved in specific functions. He famously 'mapped' the cerebral cortex, literally placing small numbered pieces of paper on those areas of cortex he had identified as responding to stimulation in particular ways (see Figure 2.28).

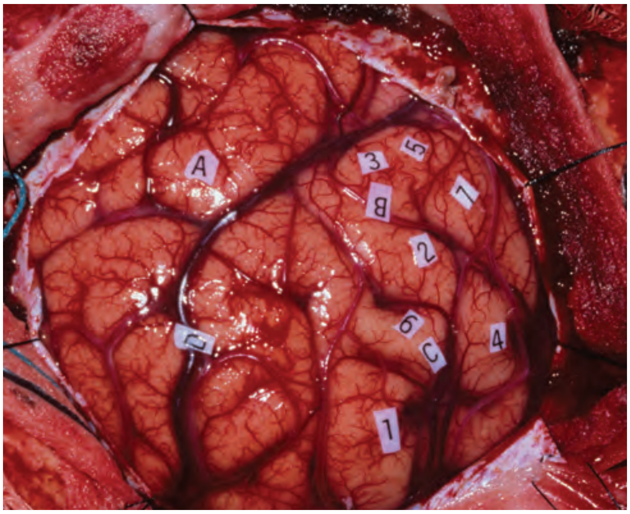


Figure 2.28 The exposed cortex of a brain during surgery, with numbered labels showing areas of the cortex that respond to stimulation in certain ways

Direct brain stimulation is often done during brain surgery where a patient is awake, so that they can respond to the effect of the stimulation, either verbally or through actions. (There are no pain receptors in the brain, so only local painkillers are required for the scalp and skull during this procedure.) This technique is useful as it can help identify which parts of the brain are involved in important functions. For example, a surgeon removing a tumour from the left frontal lobe would be cautious to avoid damaging the speech centres in and around Broca's area. By stimulating different parts of this region of the cortex and observing the effect on the patient's speech, the neurosurgeon can pinpoint the language area. When he or she then removes the tumour, the surgeon can avoid this area and try to minimise damage to this important part of the brain.

Stimulating the motor cortex may produce or inhibit (prevent) movement in the corresponding part of the body. Depending on which neurons have been affected, the stimulation may cause a particular muscle to twitch, or the patient may find they are unable to move a particular muscle. Stimulating different parts of the somatosensory cortex may result in the subject feeling sensations in the corresponding part of the body. This allows a researcher to determine which parts of the cerebral cortex are involved in which behaviours or functions.

As direct brain stimulation involves opening the skull, it is an invasive surgical procedure. It would not be recommended for every patient, given the complications that can arise from the surgery.

Transcranial magnetic stimulation (TMS)

Transcranial magnetic stimulation (TMS) is a non-surgical way of generating a map of a functioning brain. It involves using magnetic pulses to stimulate nerve cells in the brain. The resulting behaviour is observed.

TMS involves placing a device that contains wire coils on the subject's head, which produce a weak electric current via a process of induction (see Figure 2.29). The flow of currents produces a magnetic field that stimulates brain neurons directly below the coils. The subject's responses to the stimulation are observed, measured and recorded.

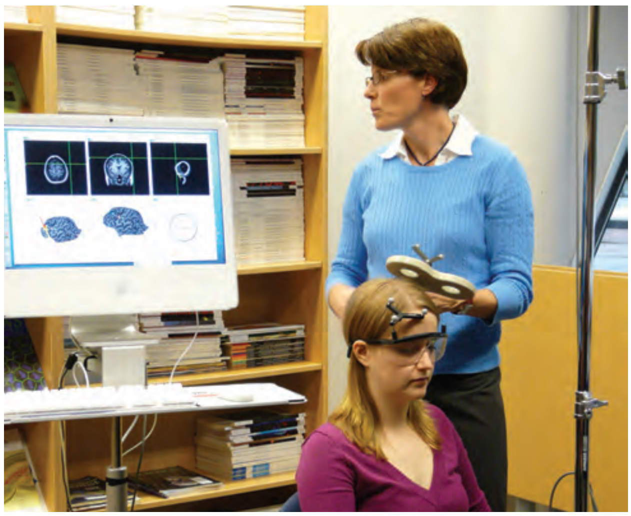


Figure 2.29 Transcranial magnetic stimulation; a device that contains wire coils is placed on the subject's head

direct brain stimulation
An invasive brain stimulation technique; involves stimulation of the brain by surgically opening the skull and delivering a measured electrical current to a specific brain area or structure

transcranial magnetic stimulation (TMS)
A non-invasive brain stimulation technique; involves stimulating the brain by delivering magnetic pulses to nerve cells in the brain

TMS is a useful method of establishing a cause-and-effect relationship between stimulation and behaviour. It also allows researchers to study the functionality of neural circuits and connectivity of the brain. TMS is commonly used with subjects who have impairments such as motor neuron disease, multiple sclerosis and stroke, to study the effects on body movement that occur when stimulating parts of the motor cortex. It allows researchers to generate a function map of the brain with minimal discomfort to the patient. Although it carries a very mild risk of seizures, overall risk to the patient is minimal.

Similar to direct brain stimulation, TMS can also act to inhibit some functions. Researchers can then draw conclusions about the effect of the part of the brain that has been inhibited and the behaviour that has been affected. However, much more research using TMS is needed to establish its usefulness in pinpointing specific brain areas responsible for specific functions. TMS has also recently been used as a treatment for chronic and severe depression, with varying results.

CHECK YOUR UNDERSTANDING 2.8

1 List one advantage and one disadvantage of each of the following brain research methods.
   a Case study
   b Direct brain stimulation
   c Transcranial brain stimulation

2 A neurosurgeon is going to operate to remove a brain tumour from the temporal lobe of a patient. The surgeon would like to conduct some research at the same time, and test which part of the temporal lobe is involved in experiencing auditory hallucinations. What sort of research would this be?
   A A survey
   B A case study
   C Direct brain stimulation
   D Clinical

3 What ethical guidelines would the surgeon in question 2 have to follow in this case?
   A Informed consent
   B Withdrawal rights
   C Protection from harm
   D All of the above

4 Could the surgeon in question 2 use brain stimulation to avoid unnecessary damage to the brain during the surgery?
   A Yes – By identifying which parts of the brain were involved in vital functions, he could hence avoid them
   B Yes – As the patient would be awake, they can indicate if the surgery is causing harm
   C No – Direct stimulation is not a precise technique
   D No – Direct stimulation is too invasive

5 Could the surgeon in question 2 use TMS instead to obtain the information he is looking for? Yes/No

BRAIN RECORDING AND IMAGING TECHNIQUES: VISUALS OF THE LIVING BRAIN

In chapter 1, we learned how the level of the brain's electrical activity can be recorded using an electroencephalograph (EEG). The EEG is a non-invasive means of providing a graphical representation of the average level of electrical activity for the whole brain. This is useful for understanding a person's state of consciousness or identifying whether their brain's electrical activity is normal. However, an EEG does not provide an image of brain structures, so it does not indicate whether a specific structure is functioning normally. To refresh your memory of the details relating to EEG function, refer to pages 18–20 of chapter 1.

Case studies and brain stimulation have been invaluable in adding to our knowledge about the brain, especially where there are few patients to study. However, rapid advances in other techniques have allowed neuroscientists to study brain structure and function in non-invasive ways and across much larger numbers of subjects.

If we need to know more about whole brain activity or specific brain structure, we need to use brain recording and neuroimaging devices. A range of neuroimaging devices now exists that allow psychologists to study *living* brains. These non-invasive devices provide either still or active images of brain areas that have provided much valuable information about the relationship between the biological and cognitive factors of human behaviour.

Computed tomographic (CT) scanning

Computerised scanning equipment has virtually revolutionised the study of brain diseases and injuries. At best, conventional X-rays produce only shadowy images of the brain. Computerised tomographic (CT) scanning, however, involves a specialised type of X-ray that provides a much clearer image (see Figure 2.30)

When undergoing a CT scan of the brain, a person has a contrast substance (iodine-based substance) injected into a vein in either their hand or arm. Because this substance is absorbed by blood vessels, it makes it easier to identify brain structures when the image is produced. Then the person lies on a bed and their head is placed into the scanner. A number of X-rays are taken from different angles and a small, harmless amount of radiation passes into their head. The amount of radiation passing through the brain when each X-ray is taken is analysed by an X-ray detector and a cross-sectional image of the brain is produced. All these images are then combined by a computer into a two-dimensional image of a cross-section of the brain.

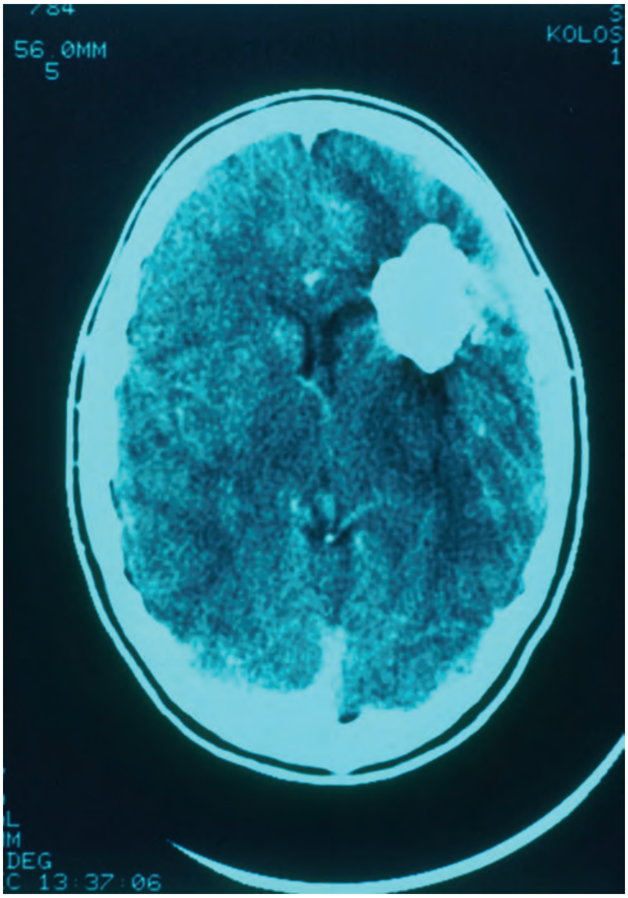


Figure 2.30 A pre-operative CT scan of a 16-year-old female's brain, showing a tumour in the frontal lobe

The CT scan, which is considered non-invasive and virtually risk-free, has been in use for nearly 40 years and has been invaluable in diagnosing structural abnormalities in brain tissue. A CT scan can reveal the location and effects of strokes, injuries, tumours and other brain disorders. These, in turn, can be related to a person's behaviour. However, the still two-dimensional image produced by a CT scan does not provide information about how the brain actually functions.

Positron emission tomography (PET)

Positron emission tomography (PET) images provide information about the living brain in action. Individuals undergoing a PET procedure have a small, harmless dose of radioactive glucose (the brain's energy source) injected into their bloodstream. They also have positron detectors placed around their head to detect positrons (subatomic particles) emitted by the radioactive glucose as it is absorbed by the brain.

The PET procedure tracks which brain areas absorb more glucose, and therefore use more energy, as tasks are being completed. The positron detectors collect the data and send it to a computer that generates a coloured image of the activity level of various brain areas during the performance of specific cognitive or behavioural tasks, such as reading, problem-solving or hand-clapping. A colour code is used to differentiate levels of brain activity. The highest level of activity (and, therefore, highest level of glucose absorption) is shown in red. This is followed by yellow, then green. Blue indicates the lowest level of activity.

Using PET, researchers can gather information about brain areas or structures involved in the performance of specific tasks as well as which areas interact when tasks are being completed. As you can see in Figure 2.31, PET scans reveal that very specific brain areas are active when you are reading a word, hearing a word, saying a word, or thinking about the meaning of a word.

PET scans provide a detailed image of the brain's biochemical processes. They are useful in detecting diseases of the brain that cause changes in the metabolism of the brain, such as tumours, strokes and dementia.

While images produced by the PET scan provide valuable information about levels of activity in different parts of the brain, the PET scan does have its limitations. The injection of radioactive sugar, although weak in concentration, is not without some risk, so PET sessions must be brief. There needs to be a 40-second interval between scans, and each scan takes approximately 30 seconds to complete, so very rapid changes in brain activity may go undetected. Also, the PET scan does not provide an image of the health level of brain areas or structures, so we cannot see any abnormality or damage – we can only see the effect of such damage on brain functioning.

neuroimaging devices
Non-invasive devices used to take still or moving images of live brains, in order to aid our understanding of brain function

computerised tomographic scan (CT)
A neuroimaging technique that takes clear X-rays of the brain at different angles to produce a computer-enhanced 2-D image of a cross-section of the brain

positron emission tomography (PET)
A neuroimaging technique involving the injection of radioactive glucose into the bloodstream, tracking the blood flow to the brain and combining this data into a series of computer-generated colour-coded images of the level of activity in various brain areas while engaged in different tasks

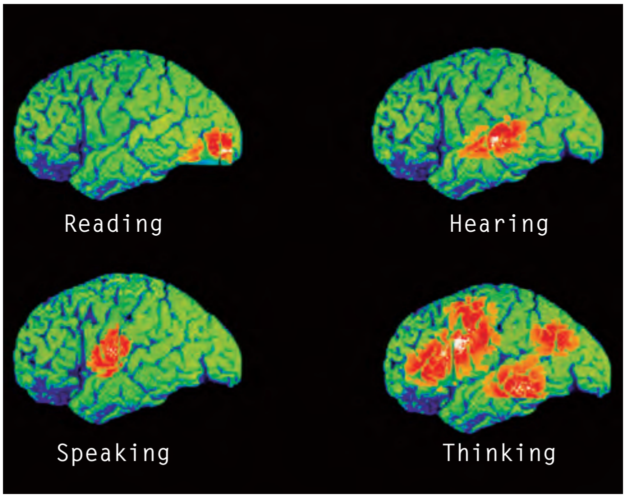


Figure 2.31 This PET scan shows which parts of the brain (seen in red) are active when reading a word silently, hearing a word, speaking a word and thinking about a word.

Single photon emission computed tomography (SPECT)

Single photon emission computed tomography (SPECT) is a type of nuclear medicine imaging procedure involving the injection of a radioactive substance (a radioisotope that emits gamma rays) into the bloodstream.

The subject lies within a large circular device that contains a specialised gamma camera. As the blood carries the radioactive substance through the brain's veins and arteries and it is used up with activity, it produces isotopes that emit gamma rays. A specialised camera detects these rays and takes numerous images of the brain that show how much blood flows through specific areas (see Figure 2.32).

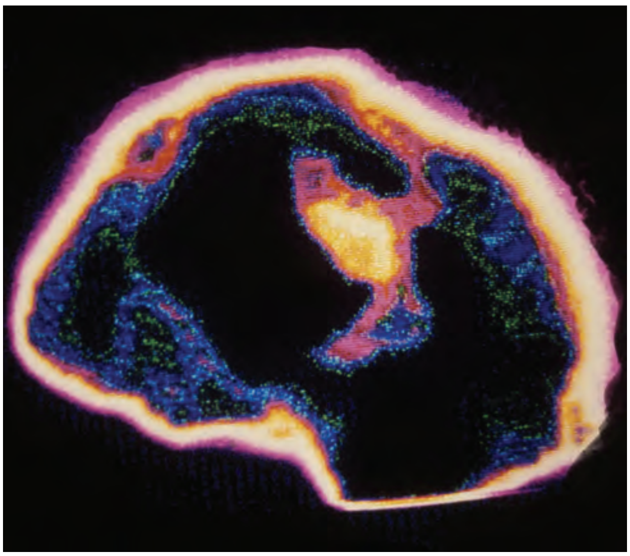


Figure 2.32 A SPECT image of the brain of an alcoholic. The non-coloured areas indicate decreased brain activity. (This is a raw SPECT image that would be combined with other similar images to form a 3-D image of the brain.)

These images are then combined by a computer to create detailed three-dimensional images of brain regions that are active during the procedure. These images can be compared to a normal blood-flow pattern involved with cognitive or physical activity.

Where a PET scan detects glucose use in the brain, the SPECT detects blood-flow to particular areas of the brain. This data is a useful indicator of injury or abnormality because it may show reduced blood-flow to a particular site. As SPECT is able to capture a moment in time in brain activity, it is especially useful in studying conditions that change from minute to minute, such as epileptic seizures. Both PET and SPECT are painless and have minimal health risks, but they produce poor resolution images.

Magnetic resonance imaging (MRI)

Magnetic resonance imaging (MRI) provides a more detailed image than the PET scan and it does not involve chemicals being injected into the bloodstream. During an MRI scan of the brain, the person's head is placed in a brace to steady it, and then they are placed inside a chamber (see Figure 2.33). This chamber creates a harmless magnetic field around their head through which radio waves are pulsed. This pulsation causes atoms in brain neurons to vibrate. These vibrations are detected by a magnet inside the chamber and the data is sent to a specialised computer. The computer combines the data to create still, detailed images of the brain (see Figure 2.34), which can then be further combined to form 3-D images if necessary.

Figure 2.33 MRI machine: The patient's head is placed inside a chamber where a harmless magnetic field is created.

MRI scans are useful for identifying any damage or abnormality associated with a brain area or structure. MRI scans can pinpoint weaknesses in blood vessels in the brain, identify cancerous cells, and pinpoint lesions caused by illnesses such as epilepsy.

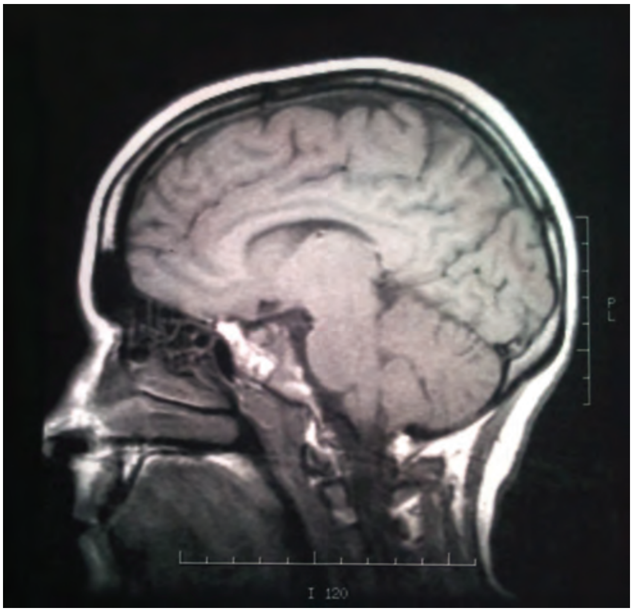


Figure 2.34 MRI image of the brain: Key brain structures can be observed in fine detail.

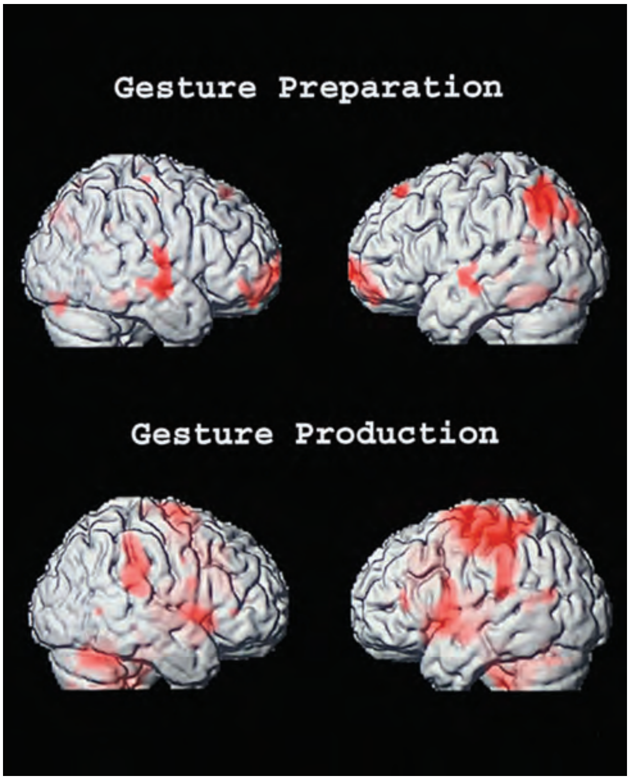


Figure 2.35 These fMRI images show areas of the brain that are active when thinking about an activity (top) and areas of the brain that are active when performing that activity.

However, because of its reliance on magnetic fields, people with metallic implants in their body, such as a pacemaker or a steel plate, cannot be given an MRI scan. Another limitation of this procedure is that although it provides a clear, still image of the brain area or structure, it does not provide active images of brain function.

View 'Videolink: MRI scan' to see an animation constructed from an MRI scan of a brain.

VIDEO
MRI scan

Functional magnetic resonance imaging (fMRI)

A functional MRI (fMRI) procedure follows the standard MRI procedure but it goes one step further by making brain activity visible. By detecting the differences between oxygenated and deoxygenated blood, an fMRI records changes in blood-flow to and from different parts of the brain as it undertakes different activities. A computer combines this data and creates a three-dimensional image of the active brain.

Psychologists use fMRI images to pinpoint which brain areas and structures are most active when a person is engaged in cognitive or physical activity (see Figure 2.35). For example, the motor cortex will be highlighted in an fMRI image when a person taps their fingers. Because the motor cortex is more active than other brain areas during a movement task, it will require more blood to flow through it, so its blood–oxygen level will be higher than that of other brain areas.

Unlike PET and CT scans, fMRI scans do not require injections, nor do they require an interval between generating images. The fact that a number of images can be generated quickly means that any rapid changes in brain activity can be detected, and the resulting information about the brain is far more detailed.

Today, still more exotic brain scanning methods are being developed. For example, a new 'diffusion weighted' MRI technique makes it possible to record changes in the connections between parts of the cortex. This should be valuable for studying learning, memory and the progress of brain diseases such as schizophrenia (Rye, 1999).

single photon emission computed tomography (SPECT)
A nuclear imaging technique involving the injection of a radioactive tracer substance into the blood stream and resulting in 3-D images of internal brain structure and functioning

magnetic resonance imaging (MRI)
A neuroimaging technique that uses a magnetic field and radio waves to vibrate brain neurons and produce a detailed, still, computer-enhanced 3-D image of brain areas or structures

functional MRI (fMRI)
A neuroimaging technique that detects changes in oxygen levels in the blood flowing through the brain and combines this data into a detailed, computer-enhanced 3-D representation of the active brain

CHECK YOUR UNDERSTANDING 2.9

1 Do these neuroimaging techniques provide information about brain structure or function or both? Copy and complete the table by placing a tick or cross in the appropriate cells.

NEUROIMAGING TECHNIQUE	STRUCTURE	FUNCTION
CT scan		
PET		
SPECT		
MRI		
fMRI		

2 List one advantage and one disadvantage of each of the following neuroimaging devices.
 a CT scan
 b PET scan
 c SPECT
 d MRI
 e fMRI

3 Which of the neuroimaging methods would be best used in the following situations?
 a To discover if there was a tumour in the brain
 b To measure the effect of stress on brain activity
 c To determine which parts of the temporal lobe are involved in storing memories
 d To identify which part of the brain has been involved in a stroke
 e To identify which part of the brain has been involved in a stroke patient who has a metal pacemaker in his heart
 f To establish which parts of the brain are used in solving complex mathematical problems

4 Sanjay has been having severe and persistent headaches and the doctor wishes to rule out a brain tumour. Which of the following techniques might the doctor use?
 A CT scan
 B PET scan
 C Case study
 D TMS

5 A neuroscientist is investigating the relationship between the frontal lobe and other parts of the brain in solving problems in secondary school students. Which neuroimaging technique would be most useful in this research?
 A CT scan
 B PET scan
 C MRI
 D fMRI

Chapter summary

WORDCHECK

TEST YOURSELF

The nervous system:

- The brain is part of the broader nervous system: the central nervous system comprises the brain and spinal cord; the peripheral nervous system comprises all those nerves that carry information between the rest of the body and the central nervous system. These nerves may be composed of sensory neurons carrying sensory information to the brain in ascending tracts or motor neurons carrying messages about movement from the brain to the body via descending tracts. The neuron is the basic building block of the nervous system.
- The peripheral nervous system comprises autonomic (and automatic) and somatic (voluntary) functions. The autonomic nervous system is important in aiding survival through its two divisions: the sympathetic division prepares us physically for action in an emergency; the parasympathetic division calms the body and restores homeostasis.

Brain processes and structure:

- Cognitive processes involve thinking, knowing or mentally manipulating information. They can be understood by learning about the structure and function of the brain.
- The brain is physically covered with an outer layer of cortex and organised into two hemispheres, separated by a deep groove (a fissure) but connected by a thick band of nerve fibres, the corpus callosum. It is also made up of four lobes in each hemisphere: the frontal, parietal, temporal and occipital lobes.
- Each lobe contains an area of cortex that specialises in a particular motor or sensory function. The frontal lobe contains the primary motor cortex, involved in producing movement; the parietal lobe contains the primary somatosensory cortex, which registers and processes sensory information from the skin and muscles; the temporal lobe contains the primary auditory cortex, which receives and processes sound information; the occipital lobe contains the primary visual cortex, which receives and processes visual information. All lobes contain areas of association cortex that integrate information between all lobes.

Hemispheric specialisation:

- Each cerebral hemisphere specialises in different functions although they work together in most instances.
- The left hemisphere specialises in verbal and analytical functions. It receives sensory information from and sends motor information to the right side of the body. The left hemisphere also contains important language centres: Broca's area in the frontal lobe is involved in the production of articulate speech; Wernicke's area in the temporal lobe is responsible for comprehension of language and the production of coherent speech. Damage to these areas causes aphasia (a language deficit).
- The right hemisphere specialises in non-verbal functions, especially visual and spatial skills. It receives sensory information from and sends motor information to the left side of the body.

The thalamus and reticular activating system:

- Two structures deep in the brain are involved in wakefulness and alertness. The *reticular activating system* is a network of neurons extending from the top of the spinal cord up to the thalamus that filters incoming sensory stimuli and influences our state of physiological arousal and alertness, and is involved in selective attention. The *thalamus* is a structure that sits on top of the brainstem through which all sensory information, except smell, passes and is redirected to the cerebral cortex for processing. Through regulating levels of sensory activity, the thalamus acts as a sensory switching station, switching excitatory or inhibitory messages on and off.

Brain studies:

- A number of important studies have contributed to our understanding of the brain's cognitive processes.
- Paul Broca studied patients with damage to the lower left frontal lobe, which resulted in impairment of the ability to produce articulate speech. The area was labelled Broca's area, and the impairment is known as Broca's aphasia.
- Carl Wernicke studied patients with an inability to understand speech or to produce coherent language. He identified part of the temporal lobe as being involved and it was labelled Wernicke's area, and the impairment is known as Wernicke's aphasia.
- Studies of patients with damage to the parietal lobe of either hemisphere have shown that it results in spatial neglect – a tendency to ignore the left or right side of one's body or the left or right side of visual space after damage to one of the brain's hemispheres.
- Roger Sperry pioneered research into the effects of a severed corpus callosum on patients and identified the specialist functions of each cerebral hemisphere. Sperry and his colleague Michael Gazzaniga conducted tests on split-brain patients, which identified the specialised language functions of the left hemisphere. They also demonstrated that the corpus callosum was responsible for integration of information from each hemisphere.

Perceptual anomalies:

- A perceptual anomaly occurs when what we perceive seems irregular and so we give meaning to the stimulus by deviating from our normal cognitive processes. Three examples illustrate this phenomenon.

- Motion after-effect occurs when we view a moving object for a period of time and then view a static object – which then appears to move in the opposite direction to the original moving stimulus. One example is the Waterfall illusion, where a waterfall appears to be moving against gravity.
- Change blindness occurs when we fail to notice large changes in a visual scene, usually because they occur at the same time as a disruption to our vision, and in particular to our attention to the visual scene.
- Synaesthesia occurs when information taken in by one sense is experienced in a way normally associated with another sense, such as a sound being experienced as a taste.

Brain research methods:

- Broca, Wernicke, Sperry and Gazzaniga conducted research called case studies. Newer techniques are now used to establish the relationship between brain structure and cognitive processes.
- Direct brain stimulation involves the surgical opening of the skull and delivering a measured electrical current (via an electrode) to a specific brain area or structure. The effect on a patient's behaviour is observed. This is considered an invasive procedure.
- Transcranial magnetic stimulation (TMS) involves using magnetic pulses to stimulate nerve cells in the brain and observing the resulting behaviour. It is considered non-invasive.

Brain recording and imaging techniques:

- The following neuroimaging devices all take and record still or moving images of the brain in relatively non-invasive ways.
- Computed tomography (CT) takes X-rays of the brain at different angles to produce a computer-enhanced image of a cross-section of the brain. It provides information about brain function.
- Positron emission tomography (PET) involves the injection of radioactive glucose into the bloodstream, tracking the blood flow to the brain and combining this data into a series of computer generated colour coded images of the level of activity in various brain areas while engaged in different tasks.
- Single photon emission computed tomography (SPECT) involves the injection of a radioactive tracer substance into the bloodstream and results in 3-D images of internal brain structure and functioning.
- Magnetic resonance imaging (MRI) uses a magnetic field and radio waves to vibrate brain neurons and produce a detailed, still, computer-enhanced 3-D image of brain areas or structures.
- Functional magnetic resonance imaging (fMRI) detects changes in oxygen levels in the blood flowing through the brain and combines this data into a detailed, computer-enhanced 3-D representation of the active brain.

Apply your knowledge and skills

SECTION A: MULTIPLE-CHOICE QUESTIONS

1 The brain and nervous system:

A are made up of billions of neurons.
B work together in an integrated way.
C are responsible for our behaviour and cognitive processes.
D All of the above.

2 The peripheral nervous system is composed of the:

A brain and spinal cord.
B sympathetic and parasympathetic nervous system.
C somatic and autonomic nervous systems.
D parasympathetic and spinal systems.

3 Which of the following is *not* true of the autonomic nervous system?

A It relays messages between the muscles that control our organs and glands and the central nervous system.
B It keeps our body in a state of homeostasis.
C It relays messages between the skeletal muscles in the body and the central nervous system.
D It functions automatically.

4 Crossing the road, Sam narrowly misses a moving car and gets a fright. Which of the following is he most likely to experience?

A An increased heart rate and respiration rate
B An increased heart rate and decreased perspiration
C A decreased heart rate and dilated pupils
D A drop in his blood pressure

5 Which branch of Sam's nervous system is dominant in question 3 above?

A The peripheral nervous system
B The spinal cord
C The parasympathetic division of the autonomic nervous system
D The sympathetic division of the autonomic nervous system

6 During surgery to remove a brain tumour, the surgeon stimulates the top of the patient's right primary somatosensory cortex. The patient is awake and will most likely experience:

A twitching in the face muscles.
B sensation around the head and neck.
C an inability to pronounce words.
D visual hallucinations.

7 Which specialised area of the cortex is involved in integrating different types of sensory information?

- **A** The primary somatosensory cortex
- **B** The primary auditory cortex
- **C** The association cortex
- **D** The midbrain

8 A person with spatial neglect will most likely:

- **A** have difficulty coordinating movements as a result of frontal lobe damage.
- **B** have difficulty recognising faces as a result of temporal lobe damage.
- **C** only recognise one side of visual space due to parietal lobe damage.
- **D** not pay attention to stimuli in the environment due to parietal lobe damage.

9 Complete this sentence with the correct words.

Broca's aphasia involves difficulty in _________ caused by damage to the __________ lobe while Wernicke's aphasia involves difficulty in __________ caused by damage to the ___________ lobe.

- **A** producing articulate speech; left frontal; understanding speech; left temporal
- **B** producing articulate speech; left temporal; understanding speech; left frontal
- **C** understanding speech; left temporal; producing articulate speech; left frontal
- **D** understanding speech; left frontal; producing articulate speech; left temporal

10 Which of the following is *most true* about hemispheric specialisation?

- **A** The left hemisphere specialises in visuospatial skills while the right specialises in analytical skills.
- **B** The left hemisphere specialises in problem-solving while the right specialises in art.
- **C** The left hemisphere specialises in mathematics while the right specialises in musical abilities.
- **D** The left hemisphere specialises in verbal functions while the right specialises in non-verbal functions.

11 The reticular activating system (RAS) is important in consciousness because it:

- **A** is involved in our sleeping and waking.
- **B** bombards the cortex with important sensory information keeping it alert and active.
- **C** allows us to focus attention on important stimuli and ignore others.
- **D** All of the above

12 Which is the best definition of a perceptual anomaly?

- **A** A visual illusion
- **B** A distortion in perception arising from a confusing stimulus
- **C** A misinterpretation of a stimulus
- **D** A deviation from the normal cognitive processes that results in a perceptual irregularity

13 Synaesthesia, a perceptual anomaly, is best explained by:

- **A** the brain's failure to remove excess neurons early in life.
- **B** confusion that results from sensory overload.
- **C** nothing; there is no clear explanation despite extensive research.
- **D** that fact that synaesthetes have extra neural connections in the brain.

14 One advantage of direct brain stimulation as a research method is that:

- **A** the patient can be awake during the procedure.
- **B** it is non-invasive.
- **C** there are very few ethical considerations that need to be considered.
- **D** a direct relationship between the brain part being stimulated and the effect on the patient can be observed.

15 Which neuroimaging technique allows a study of both brain structure and function?

- **A** CT scan
- **B** PET scan
- **C** MRI
- **D** fMRI

SECTION B: SHORT-ANSWER QUESTIONS

1 State two major functions of the human nervous system.

2 You are about to make a speech at your school presentation night and you feel very nervous.

- **a** List three physical symptoms you would experience as a result of the activation of your sympathetic nervous system.
- **b** How could you influence your autonomic nervous system so you remain calm?

3 List four important functions of the frontal lobes of the brain.

4 What behavioural changes would you observe in a person whose corpus callosum had been severed?

5 Explain the role of the reticular activating system in attention.

6 How could you determine whether a patient was suffering from Broca's aphasia or Wernicke's aphasia?

7 Explain the key findings of the research conducted by Sperry and Gazzaniga in three dot points.

8 a Describe change blindness.
   b Explain why it occurs.
   c Provide one example of where it is a limitation.

9 Outline the key differences between the brain research methods of direct brain stimulation and TMS, and the neuroimaging techniques.

10 Choose one brain research technique and:
   a describe an area of research it would be useful for.
   b name one ethical consideration that would apply to this technique.
   c state one advantage of this technique over others.

SECTION C: EXTENDED-RESPONSE QUESTION

Imagine that a large black spider drops onto this textbook as you are reading it. Describe your reaction in terms of the role and function of the autonomic nervous system. In your response, ensure you distinguish between the roles and functions of the different branches of the autonomic nervous system.

This question is worth 10 marks.

SECTION D: ASSESSMENT TASK

VISUAL PRESENTATION

This activity will draw together students' understanding of the relationship between brain structure and cognitive processes in a visual presentation.

Aim

Create and present a visual presentation of the brain demonstrating the function of the lobes, primary cortices and hemispheres, with illustrations. Your presentation should stand alone as an explanation of the relationship between brain structures and functions.

Audience

VCE students

Materials

Either a large sheet of poster paper and coloured pens or multimedia software program

Method

Your presentation can be in the form of either a poster or a multimedia presentation.

Your presentation should clearly show each structure or brain area listed below. It must also label/explain the function of each structure of brain area.

- Whole brain
- Left and right hemispheres
- Four lobes – frontal, parietal, temporal and occipital
- Primary cortex in each lobe – motor, somatosensory, auditory, visual, association areas
- Language centres – Broca's area, Wernicke's area
- Deeper brain structures – thalamus, reticular activating system.

One illustration of each function should be provided visually. If using a multimedia format, this could be a still or moving image. For example, you might show a pair of walking legs to illustrate the function of the primary motor cortex.