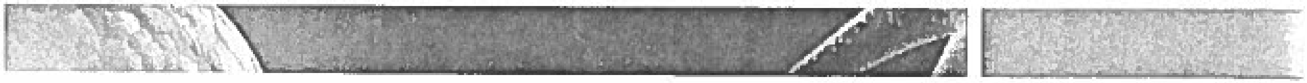


Essential ideas

A.1 Modification of neurones starts in the earliest stages of embryogenesis and continues to the final years of life.

A.2 The parts of the brain specialize in different functions.

A.3 Living organisms are able to detect changes in the environment.

Active neurones in the brain are communicating using chemical messaging.

Do video games have a long-term effect on brain functioning? Does learning a second language make your brain more efficient? Scientists, using both animal models and new technologies, are now discovering the answers to these questions. For example, Yang Wang, a radiologist from the School of Medicine in Indiana, is using functional magnetic resonance imaging (fMRI) to study the brains of young adults watching violent video games. Technology has also given us the ability to collect data on how neurones migrate in the developing brain and communicate with each other. We now know that the brain is plastic throughout our lives. It keeps on being moulded through new experiences, like learning a new language. Research on how drugs affect the brain has allowed medications to be developed that improve the lives of people with biochemical imbalances. Animal models have helped us understand the problem of addiction.

The study of neurogenesis in the embryonic brain has provided us with data showing that neurones are producing and responding to chemical messages. Nerve cells communicate with each other using molecules. As the immature nerve cells migrate to their final home and the brain matures, millions of connections are formed and then lost. Those connections that are reinforced by experience remain as learning and memory.

A.1 Neural development

NATURE OF SCIENCE

Use models as representations of the real world: developmental neuroscience uses a variety of animal models.

Understandings:

- The neural tube of embryonic chordates is formed by infolding of ectoderm followed by elongation of the tube.
- Neurones are initially produced by differentiation in the neural tube.
- Immature neurones migrate to a final location.
- An axon grows from each immature neurone in response to chemical stimuli.
- Some axons extend beyond the neural tube to reach other parts of the body.
- A developing neurone forms multiple synapses.
- Synapses that are not used do not persist.
- Neural pruning involves the loss of unused neurones.
- The plasticity of the nervous system allows it to change with experience.

Applications and skills:

- Application: Incomplete closure of the embryonic neural tube can cause *spina bifida*.
- Application: Events such as strokes may promote reorganization of brain function.
- Skill: Annotation of a diagram of embryonic tissues in *Xenopus*, used as an animal model, during neurulation.

Guidance

- *Terminology relating to embryonic brain areas or nervous system divisions is not required.*

Neural tube formation

Have you ever wondered how all the organs in our body form from just one fertilized egg? The study of this development, from a fertilized egg to a fully formed organism, is called embryogenesis. Scientists have come to understand the processes of embryogenesis by studying various animal models. Because the ultimate goal is to understand embryogenesis in humans, animals in the same phylum with similar developmental patterns have been studied. Humans belong to the phylum Chordata (chordates) and are in the subphylum Vertebrata (vertebrates). Vertebrates, which include fish, amphibians, reptiles, birds, and mammals, are all therefore considered as possible animal models. A frog is an animal that has been studied extensively because it is (or was) readily available and can be collected from local ponds by scientists. During the earliest part of the 20th century, chicks were added to the study of embryogenesis. Birds are warm-blooded vertebrates, and fertile chick eggs are available all over the world for scientists to use, with very little expense involved. Historically, scientists moved away from the study of 'lower' chordates such as frogs to the study of 'higher' chordates such as chicks, with the aim of understanding normal and abnormal embryogenesis.

One of the benefits of these studies of embryogenesis is that it enabled scientists to learn the key principles of neural development. Using the frog embryo as an example, we can see how the nervous system of an embryonic chordate develops.

After fertilization, cells of the frog embryo develop into three distinct tissue layers: the outermost layer (ectoderm), which will become the brain and nervous system of the adult frog; the inner layer (endoderm), which forms the lining of the gut and the lining of other organs; and the middle layer (mesoderm), which develops into the skeletal, reproductive, circulatory, excretory, and muscular system of the adult frog. A cavity in the centre of the frog (*Xenopus*) embryo is a primitive gut called the archenteron.

Table 7.1 The names of the three embryonic tissue layers of *Xenopus* (a frog)

Ecto (outer)	Derm (skin)
Meso (middle)	Derm (skin)
Endo (inner)	Derm (skin)

From these layers, one of the first organs to develop is the neural tube, which will eventually become the brain and spinal cord of the frog. In embryos, the presence of one tissue that is developing causes the development of another tissue. In this case, the presence of the notochord, a mesodermal tissue, causes the ectoderm to develop into a neural plate. As embryogenesis continues, the neural plate folds in, closes, and becomes the neural tube. The neural tube then elongates and becomes the brain and spinal cord of the frog.

Here is a picture of the embryonic tissues of *Xenopus* (a species of frog).

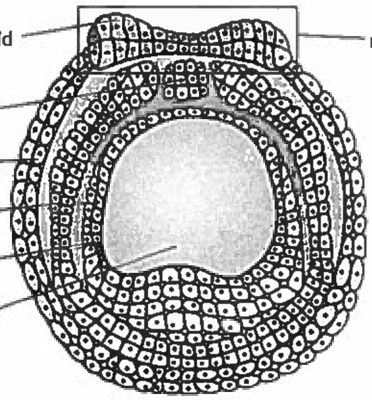


Figure 7.1 Embryonic tissues in *Xenopus*. Campbell and Reece 1999

CHALLENGE YOURSELF

1 Redraw the picture of the embryonic tissues of *Xenopus* and label it without looking at Figure 7.1. Annotate the figure you have drawn. To annotate you must describe the fate of each part as it develops into the adult *Xenopus* frog. Annotate using a table of your own design.

NATURE OF SCIENCE

What are model organisms? Model organisms are organisms that are easy to study, and are used widely by scientists studying in a similar field. The following table will give you an idea of what organisms provide good models for particular studies, and why.

Table 7.2 Examples of model organisms

Field of study	Characteristics needed for the model/why the species provides a good model	Suitable species
Genetics	Large numbers and short generation times	Fruit fly Baker's yeast Nematode worm
Developmental biology	Robust embryos that are easily manipulated	Chicken African clawed frog (*Xenopus*)
Genomic studies, such as genes that cause diseases	60% of human genetic diseases studied have a counterpart in the fruit fly and nematode	Fruit fly Nematode
Comparative genomics	The mouse genome is similarly organized to the human genome	Mouse

To learn more about model organisms, go to the hotlinks site, search for the title or ISBN, and click on Chapter 7: Section A.1.

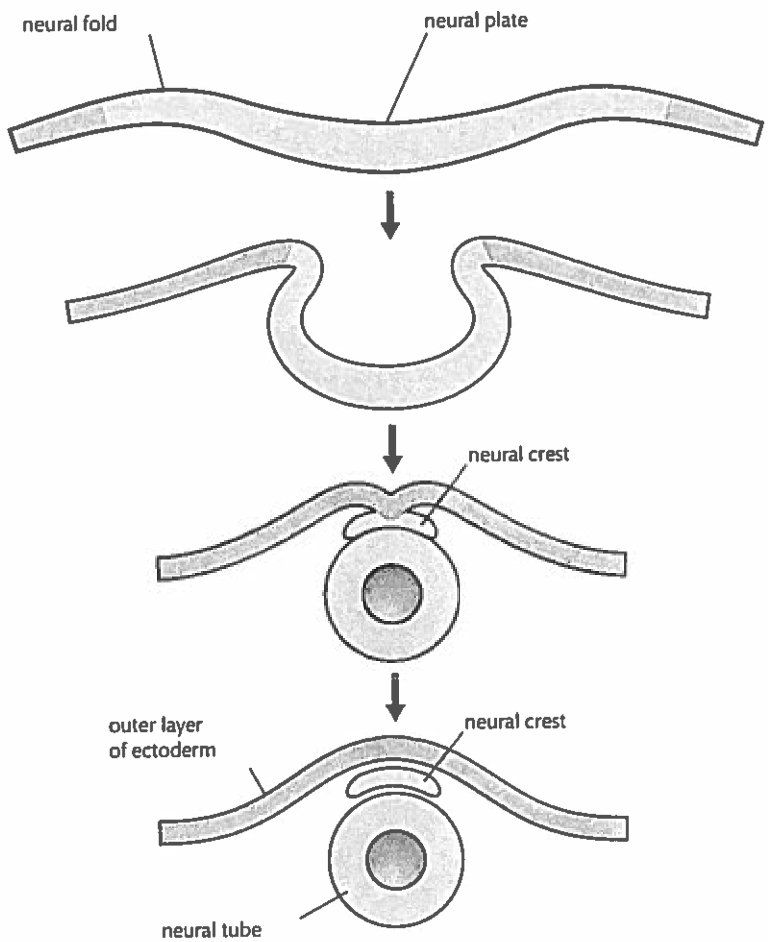


Figure 7.2 Formation of the neural tube from the neural plate Campbell and Reece 1999

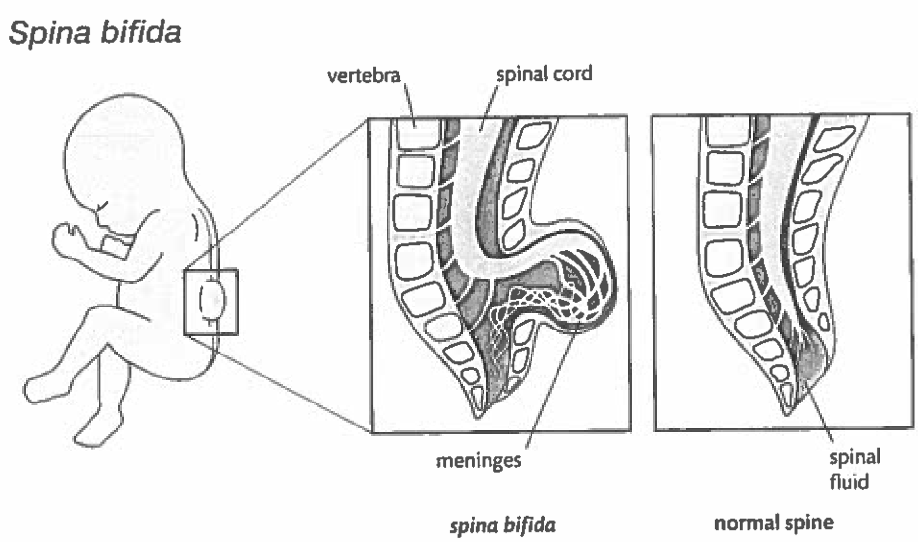


Figure 7.3 *Spina bifida* is caused by incomplete closing of the neural tube. http://babygilbertfund.com/

The closure of the neural tube does not take place simultaneously all along the body of the embryo. The area where the brain forms is well advanced compared with the caudal (tail) area. Closure of the neural tube in the tail area occurs more slowly and may not even completely close during embryonic development. This failure to close the human posterior (caudal) neural tube at day 27 of development results in the condition of *spina bifida*. How severe this is depends on how much of the spinal cord remains exposed.

Closure of the human neural tube seems to be controlled by a combination of genetic and environmental factors. Certain genes have been found to control the formation of the mammalian neural tube, but dietary factors also seem to be critical. The US health service recommends that women take supplemental folic acid during pregnancy to prevent neural tube defects. One estimate suggests that using vitamin B_{12} as a supplement can prevent 50% of neural tube defects.

Neurogenesis and migration of neurones

The neurones of the central nervous system (CNS) in the developing vertebrate embryo originate in the neural tube. Neuroblasts are immature neurones that are the precursor cells of neurones. The process of differentiation from neuroblast to neurone is called neurogenesis. As soon as the neural tube begins to transform into specific brain parts, two major families of cells begin to differentiate. These two types of cells are neurones and glial cells. Neurones carry messages, while glial cells do not carry messages. Ninety per cent of brain cells are glial and have many functions. One important function is physical and nutritional support of the neurone. Most of the new neurones in the human cortex are formed between the fifth week and the fifth month of development.

Helen Cooper and her team at the Queensland Brain Institute have identified signalling molecules that may be used to promote the birth of new neurones, which will then migrate to damaged regions of the brain. This could be a major step forward in achieving functional recovery in a damaged brain.

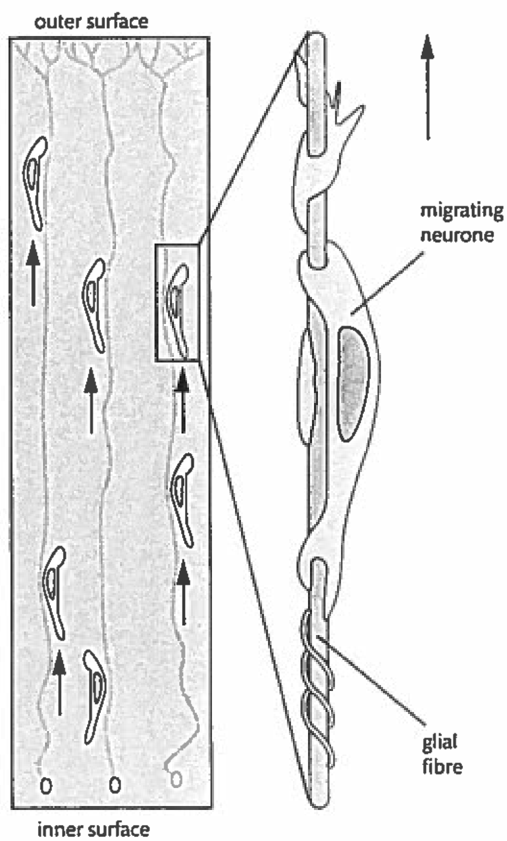


Figure 7.4 Scaffolding glial cells allow neurones to reach their final destination.

Neuroblasts are cells in the embryo that will become neurones.

Two cell types formed by neurogenesis are neurones, which carry messages around the brain, and glial (glue) cells, which provide the support and the nutrition for the neurones.

Glial cells provide a scaffolding network along which the immature neurones migrate. Along this scaffolding of the glial cells, immature nerve cells can migrate to their final location, mature, and send out their axons and dendrites.

'Glia' means glue in Greek. The word neurogenesis comes from 'neuro' meaning nerve cell and 'genesis' meaning beginning.

Axon growth

As the neurone grows, it will send out one long axon moving towards a distant area. At the tip of the axon is a growth cone, which directs the axon. In cell cultures it is possible to watch axons grow. When an axon contacts an unfavourable surface it contracts, but with a favourable surface it persists. An axon can move forward at about 1 mm a day.

When neurones have reached their final location, synaptic connections must be made with their target cells. These target cells produce chemical messages that the neurone responds to. The signal molecule from the target cell can be secreted into the extracellular environment or carried on the target cell's surface. The neurone responds to the chemical messages by forming synapses with the target cell.

Certain molecules from the target cell can act as signals to the growth cone. One type of signal molecule is called a cell adhesion molecule (CAM). CAMs are located on the surface of cells in the growth environment of the axon. The growth cone of the axon has a receptor called a CAM-specific receptor, so that when a CAM and its receptor recognize each other, chemical messaging takes place within the neurone. This results in the activation of enzymes within the neurone that contribute to the elongation of the axon.

Some receptors on a growth cone can also pick up the signal of molecules secreted by the target cell that diffuse into the extracellular environment. These are called chemotrophic factors. These factors can be attractive or repellent. Chemoattractive factors attract the axon to grow towards it. Chemorepellent factors repel the axon, so that the axon will elongate in a different direction. The growth cone responds to the various chemical stimuli that show it what path to follow and what connections to make.

TOK: For more than 100 years scientists believed that glial cells did not play a role in neurotransmission. Only as recently as 2010 was this idea shown to be false. Why is the idea of falsification important to scientific knowledge?

Axons of the neurone contact a favourable surface.

Axons grow 1 mm per day.

Axons respond to chemical messages from the target cell.

Axons form synapses with the target cell.

The signal molecule from the target cell is called CAM.

The growth cone of the axon has CAM-specific receptors. (A mnemonic device is: Can the Axon Make it to the right target using its receptors).

The target cell also secretes chemoattractive or chemorepellent factors.

The axon will grow towards the target cell if the message is chemoattractive.

Can you draw a labelled cartoon to help you remember the steps of axon growth?

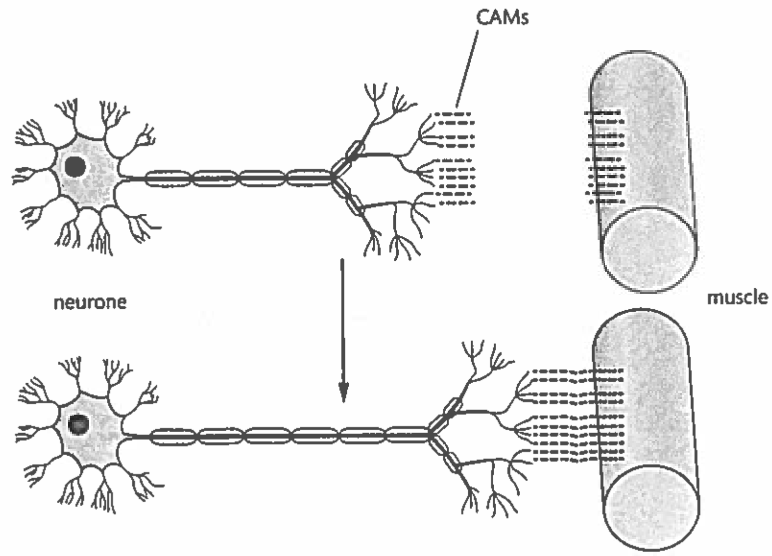


Figure 7.5 Signal molecules called CAMs attract the axons to their target muscle cells.

Some axons extend beyond the neural tube

Some neurones, for example mammalian motor neurones, have to send their axons out of the area of the neural tube and travel much further in their journey towards other target cells. This gives the mammal the ability to control voluntary muscular movement. The motor neurones must extend their axons out of the CNS (the brain anc

Neuroblasts differentiate into neurones. Neurones grow towards their target cells. The target cells give chemical signals, e.g. CAM, to the neurone.

spinal cord) in order to form these circuits. Newly developed motor neurones, which extend axons from the spinal cord, are some of the longest neurones in the body. During embryogenesis, these cells follow the same pathways to synapse with muscle targets as other neurones located within the CNS. The muscles that need to attract the axons will produce CAMs. The CAM receptor in the axon will activate enzymes to cause the growth cone of the axon to grow towards the muscle.

Even new muscle cells in the embryo are producing CAM, attempting to attract a growing neurone from the spinal cord.

The growth cone in the axon will respond by growing towards the muscle cell.

Multiple synapses

A huge number of synapses are formed during early brain development. Imagine if you could not remember your password and were desperate to download a movie. You would try all of the passwords you have ever used until one of them worked perfectly. A developing neurone does the same sort of thing, trying out all the possible connections to see which is the best fit. A single nerve cell can make a myriad of connections with its neighbouring nerve cells at the many points of branching that radiate from the main cell body. Not every cell will be the best partner. The job of the neurone is to find the best fit. In other words, only those synapses that have a function will survive, and the rest will gradually weaken until they disappear. Just think how easy it is to forget a password that you never use.

An axon that begins in the spinal cord and innervates a muscle in the foot can be as long as 1 m (3 feet).

The neurones of the brain try to form a synapse with any nearby target cell, and then attempt to test out the connection. Will the connection work? Many do not, and those connections are eliminated. When the connections are between functionally compatible neurones, the result is a strengthening of communication.

Neuroscientist Z. Josh Huang, at Cold Springs Harbor Laboratory, in an article published in the *Journal of Neuroscience*, described the behaviour of neurones making tentative connections with almost every available partner. Lots of partners are tried, and eventually one is found that is compatible. Huang goes on to state that one mechanism at work during these rapid connections is controlled by a type of neural adhesion molecule that is recruited to the site of the connection. This adhesion molecule is also a type of CAM, called immunoglobulin CAM (IgCAM), and it acts like a lock and key. CAMs form a physical but reversible glue-like bond between the tentative projection of one cell's axon and the receiving structure on a neighbouring cell. Eventually, many of these connections are lost because it turns out they are not with the right partner cell.

The word synapse is 113 years old. It was first coined in a textbook of physiology written in 1897. The author, Michael Foster, derived the word from the Greek words 'syn' and 'haptein', which mean together and clasp, respectively.

Some synapses do not persist

Just as you would not use any passwords that do not work, the neurone will not keep any synapses that do not work. Most of our information about how the growth cones of an axon find their way to the target cell comes from the study of neurones that have travelled to a muscle from the spinal cord. Where they connect is called the neuromuscular junction. The axons form synapses that compete for the ability to innervate a muscle fibre. Specific molecules from the neurones and muscles facilitate these connections. The strongest connection will survive, and the rest are eliminated.

A muscle fibre is the site of a heated competition, with multiple synapses trying to win. Eventually, the connection made will be the best one between one motor neurone and the muscle fibre. As development proceeds, the other synapses are eliminated. Finally, the strength of the remaining synapse is increased. This is how the circuitry of the nervous system is formed.

Neural pruning

Pruning results in the overall number of neurones being reduced. When an infant is 2 or 3 years old, he or she has 15 000 synapses per neurone. This is twice as many as in an adult brain. Neural pruning eliminates axons that are not being used. The purpose of neural pruning seems to be to remove the simpler connections made in childhood and replace them with the more complex wiring made in adulthood. As we have seen with other descriptions of neurone activity, pruning seems to follow the 'use it or lose it' principle. Synapses that are rarely used are eliminated, and those with strong connections are maintained. The removal of unneeded connections leads to improvement in brain efficiency.

Scientists supported by the National Institutes of Health in the USA have been studying pruning using the mouse as a model organism. They have discovered that cells called microglia, a type of glial cell, can prune unused synapses. This precise elimination of synapses that are unused and the strengthening of the more active synapses is a key part of normal brain development. Researchers hypothesize that microglia select a synapse for removal based on the inactivity of the synapse.

If a young child is deprived of stimulation, certain neurone pathways and synapses may be discarded. This is neural pruning. Synapses that are highly active will be preserved, while those that are underactive will be pruned. As we have seen, a 2–3-year-old child has the most synapses. Early childhood is the best time to learn language skills, when the excess synapses provide the raw material for the language experience to act on. Research into bilingualism suggests that exposure to more than one language is an excellent means of cognitive strengthening when young.

Worked example

What is neural pruning and why is it important?

Solution

The neurones of the brain try to form a synapse with any nearby target cell and then attempt to test out the connection. Will the connection work? Many do not and the connection is eliminated. This is neural pruning. When the connections are between functionally compatible neurones, the result is a strengthening of communication.

The purpose seems to be removal of the simpler connections of childhood and replacement by more complex wiring present in adulthood.

The plasticity of the nervous system

Brain plasticity is the concept, now widely accepted, that the brain has the ability to change and adapt as a result of experience. Until 1960, researchers believed that only the brain of an infant or child could change, and that by adulthood the brain was unchangeable. Modern research has demonstrated that the adult brain does have plasticity. It can rewire itself after suffering massive strokes. Today we understand that the brain can create new neurones and new pathways. Scientists have shown that plasticity can vary with age, and that it is influenced by both environment and heredity. Thus we now know that the brain and nervous system are not static as previously thought.

To learn more about brain plasticity, go to the hotlinks site, search for the title or ISBN, and click on Chapter 7: Section A.1.

The brain exhibits two types of plasticity: functional and structural. Functional plasticity is the ability of the brain to move functions from a damaged area to an undamaged area. Structural plasticity refers to the fact that the brain can actually change its physical structure as a result of learning.

An example of a functional shift can be illustrated by studying a tennis player who has suffered a stroke and has a paralysed left arm. During his rehabilitation, his good arm and hand are immobilized by the physical therapist, so that he can't use them.

The tennis player is then given the task of cleaning tables. At first the task is impossible for him, but slowly his bad arm begins to remember how to move, and eventually he is back playing tennis. The functions in the brain areas that were killed by the stroke are transferred to healthy regions. New connections are formed between the intact neurones; these neurones are stimulated by activity.

An example of a structural shift in the brain is has been shown in a study of London taxi drivers by McGill University scientists. By observing London taxi drivers using magnetic resonance imaging (MRI) techniques to obtain images of their brains, the scientists discovered that experienced drivers have a larger hippocampus area in their brain than other drivers. This seems to be because their job needs their brain to store large amounts of information and to have good spatial understanding. London taxi drivers have to pass an extensive test on 320 standard routes throughout the city before they can start working. Most drivers prepare for the test over 34 months by practising the routes on a moped. MRIs have shown a structural change in the hippocampus of these taxi drivers, which increases with the length of time a driver has been doing the routes.

Worked example

What is adult brain plasticity? What is the difference between structural and functional plasticity?

Solution

- The adult brain can change and adapt as a result of experience.
- The adult brain can rewire after a massive stroke.
- Functional plasticity is the ability to move functions from a damaged area to an undamaged area.
- Structural plasticity means that the brain can actually change its physical structure as a result of learning.

Stroke may promote reorganization of brain function

Neuroimaging studies on stroke patients suggest that functional and structural reorganization of the brain takes place during recovery. This includes axon sprouting (new connections between axons), post-stroke neurogenesis (migration of new neurones to the site of the injury), differentiation of immature glial cells, and new associations with neurones and blood vessels.

Does the brain do this all by itself, or do we have some input into how this reorganization takes place? We know that after a stroke there are both chemical and physical changes in the pathways. What can be done to promote recovery?

In animal models with primates, it has been shown that improvement can be made with intervention. After a stroke resulting in weak hand movement in monkeys, the monkeys that did exercises with food rewards improved more rapidly than those that did not exercise. The part of the brain that improved shoulder movement took over the movement of the hand. The brain had reorganized itself in those monkeys that had received therapy.

In addition to animal models, new technologies have increased our knowledge of how the brain recovers from a stroke. Functional magnetic resonance imaging (fMRI), positron emission tomography (PET), brain mapping (magnetoencephalography, MEG) and other technologies have unravelled the many brain changes that take place in response to rehabilitation strategies and drugs. A common condition that results from a stroke is partial or complete loss of language function, called post-stroke aphasia (PSA). It had been estimated previously that the window for improvement of PSA was the first year following the stroke. Results of modern brain imaging studies have demonstrated that the recovery of language function can occur well beyond this period. These brain imaging and mapping techniques help clinicians and researchers design better strategies to enhance recovery.

Worked example

Can you remember? Write the correct term to describe each of the following statements.

1 An animal model used in the study of neurulation.
2 Can result in both structural and functional reorganization of the brain.
3 The ability of the brain to move from a damaged to an undamaged area.
4 The ability of the brain to change its physical structure.
5 Elimination of axons not being used.
6 The brain can rewire after a stroke.
7 Incomplete closure of the neural tube.

Solutions

1 *Xenopus.*
2 Stroke.
3 Functional shift.
4 Structural shift.
5 Neural pruning.
6 Plasticity.
7 *Spina bifida.*

Two Mayo Clinic scientists have worked as a team to address the problem of regeneration of nerve tissue in spinal cord injury patients. Anthony J. Windebank, a neurologist, has implanted stem cells into damaged nerve tissue. He manipulated the stem cells so that they would promote nerve regeneration. The stem cells delivered the neural growth factors needed for nerve regeneration, but something else was needed for the spinal cord injury to be repaired. In order for the axons to find and connect with an appropriate target cell, a scaffold was needed. Michael J. Yaszemski, a biomedical engineer, was able to create such scaffolding. He designed tubing that acts as a synthetic, biodegradable scaffold. This scaffold can connect severed axons. Working together, these two scientists have pioneered a technique to insert stem cells into scaffold implants in injured spinal cords in animals. Eventually, this work will proceed to human trials.

TOK

Gregoire Courtine, who works at the Brain Mind Institute in Switzerland, has decided to switch the paradigm for those who have spinal cord damage and paraplegia. The switch is to change the view of the patient from a 'non-functioning person' to a 'person who is in a dormant state'. He describes his idea by imagining an injured patient as a car with all the parts (muscle, bone, etc.) present but the engine turned off. His goal is to produce a pharmaceutical cocktail to prepare the nerves for stimulation. Next he will surgically implant a mechanical object that will communicate between the brain and the spinal cord. Eventually the person will be able to move and walk again. He has called his research programme the 'rewalk' programme. How is this a new paradigm of how paraplegics are viewed?

Section summary

- Neurogenesis is the development of the brain and spinal cord from the ectoderm of an embryo. The ectoderm folds into the neural tube. Nerve cells (neurones) are formed by differentiation from the neural tube.
- Neurones grow towards target cells. Neurones respond to chemical messages produced by the target cells. The chemical messages are called CAM.

To learn more about work with spinal cord injuries and see the work of Professor Courtine, go to the hotlinks site, search for the title or ISBN, and click on Chapter 7: Section A.1.

- **During brain development a large number of synapses are formed between neurones. Only the strongest synapses are used and strengthened and the rest are eliminated. Elimination of some connections is called neural pruning.**
- **Modern research has shown that brains of all ages have plasticity. Functional plasticity is the ability of the brain to move functions from a damaged area to an undamaged area. Structural plasticity means that the brain can change its physical structure as a result of learning.**

Always include examples in answers to compare and contrast questions. Remember that compare and contrast means to give similarities and differences between two or more items, referring to both of them throughout.

Exercises

1. Describe *spina bifida*.
2. Outline the differentiation and migration of immature neurones.
3. Explain neural pruning.
4. Compare and contrast functional and structural plasticity of the brain.

A.2 The human brain

NATURE OF SCIENCE

Use models as representations of the real world: the sensory homunculus and motor homunculus are models of the relative space human body parts occupy on the somatosensory cortex and the motor cortex.

Understandings:

- The anterior part of the neural tube expands to form the brain.
- Different parts of the brain have specific roles.
- The autonomic nervous system controls involuntary processes in the body using centres located mainly in the brainstem.
- The cerebral cortex forms a larger portion of the brain and is more highly developed in humans than other animals.
- The human cerebral cortex has become enlarged principally by an increase in total area with extensive folding to accommodate it within the cranium.
- The cerebral hemispheres are responsible for higher order functions.
- The left cerebral hemisphere receives sensory input from sensory receptors in the right side of the body and the right side of the visual field in both eyes, and vice versa for the right hemisphere.
- The left cerebral hemisphere controls muscle contraction in the right side of the body, and vice versa for the right hemisphere.
- Brain metabolism requires large energy inputs.

Applications and skills:

- Application: Visual cortex, Broca's area, nucleus accumbens as areas of the brain with specific functions.
- Application: Swallowing, breathing, and heart rate as examples of activities coordinated by the medulla.
- Application: Use of the pupil reflex to evaluate brain damage.
- Application: Use of animal experiments, autopsy, lesions, and fMRI to identify the role of different brain parts.
- Skill: Identification of parts of the brain in a photograph, diagram, or scan of the brain.
- Skill: Analysis of correlations between body size and brain size in different animals.

Guidance

- *Image of the brain should include the medulla oblongata, cerebellum, hypothalamus, pituitary gland, and cerebral hemispheres.*
- *Although specific functions can be attributed to certain areas, brain imagery shows that some activities are spread in many areas, and that the brain can even reorganize itself following a disturbance such as a stroke.*

The neural tube expands to form the brain

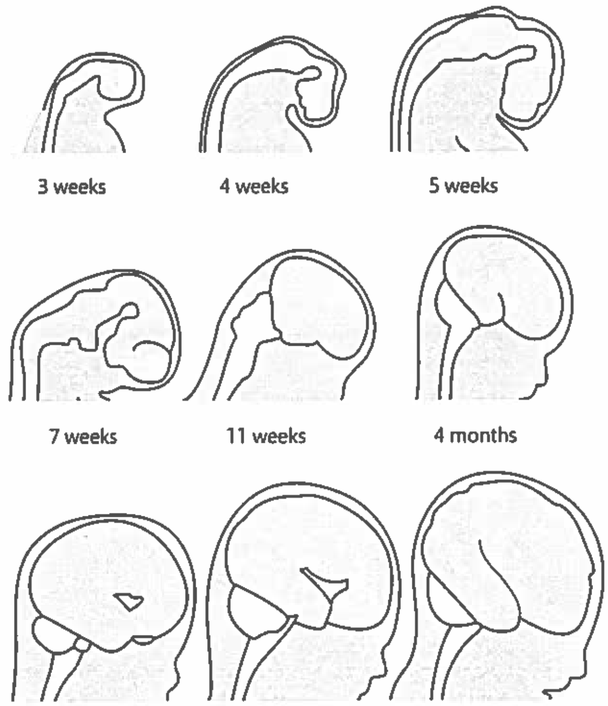


Figure 7.6 The neural tube expands to form the brain.

From the study of neurogenesis in Section A.1, you should now be familiar with the neural tube and how it is formed. To form the brain, nerve cells migrate to the outer edge of the neural tube and cause the walls to thicken. Eventually, the neural tube develops into the entire central nervous system: the brain and the spinal cord. The anterior end of the neural tube (forebrain) expands dramatically into the cerebral hemispheres. The posterior end of the neural tube develops into the other brain parts and the spinal cord. Neural development is one of the first systems to begin developing and one of the last systems to finish developing before birth. Brain development is one of the most complex systems in the embryo.

Researchers from the University of Texas Health Science Center in San Antonio have reported that eating less during early pregnancy impairs foetal brain development in a non-human primate model.

Different parts of the brain have specific roles

The brain is the most complex organ in the body. This jelly-like group of tissues, weighing 1.4 kg, produces our thoughts, feelings, actions, and memories. It contains an amazing 100 billion neurones, with thousands of synapses making the amount of connectivity literally mind-boggling. New connections are formed every day of our lives. These new connections store memories, learning, and personality traits. Some connections are lost and others are gained. No two brains are identical, and your brain continues to change throughout your life.

The brain regulates and monitors unconscious body processes such as blood pressure, heart rate, and breathing. It receives a flood of messages from the senses, and responds by controlling balance, muscle coordination, and most voluntary movement. Other parts of the brain deal with speech, emotions, and problem solving. Your brain allows you to think and dream.

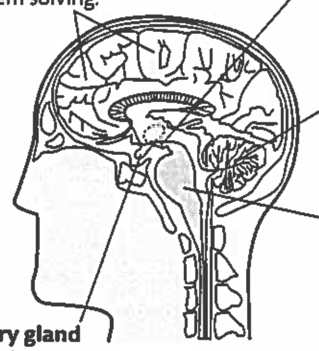


Figure 7.7 Parts of the human brain.

The following bullet points would be suitable text for annotating a diagram of the brain.

- Cerebral hemispheres act as the integrating centre for higher complex functions such as learning, memory, and emotions.
- The hypothalamus maintains homeostasis, coordinating the nervous and the endocrine systems. It synthesizes hormones which are stored in the posterior pituitary and releases factors regulating the anterior pituitary.
- The cerebellum is often called 'the little brain' because it has two hemispheres and a highly folded surface. It coordinates unconscious functions, such as movement and balance.
- The medulla oblongata controls automatic and homeostatic activities, such as swallowing, digestion, vomiting, breathing, and heart activity.
- The pituitary gland has two lobes, the posterior lobe and the anterior lobe. Both are controlled by the hypothalamus, and both produce and secrete hormones regulating many body functions.

Role of the medulla

The medulla oblongata contains a 'swallowing centre' that coordinates the muscles of the mouth, pharynx (throat), and larynx (Adam's apple), so that a bolus of food will move down the oesophagus to your stomach during swallowing, and not down your windpipe (trachea).

The medulla oblongata controls breathing by monitoring the level of carbon dioxide in the blood. If there is an increase in carbon dioxide (meaning low oxygen), the rate and depth of breathing are increased so that more oxygen is take in.

The medulla oblongata is also the cardiovascular centre for the body. The heart rate will slow down if it is activated by the cardioinhibitory centre or speed up if it is activated by the cardioaccelerator centre. When you first begin to exercise, the cardioinhibitory centre stops causing an increase in heart rate. During more strenuous exercise, the heart rate increases by direct stimulation of the cardioacclerator centre.

CHALLENGE YOURSELF

2 Study Figure 7.7, then try to draw a picture of the brain without looking at it.
- After you have drawn the picture, put on the labels.
- Every label must have a line leading exactly to the part it is referring to.
- Use straight lines and a ruler. Never use arrowheads when labelling. Only use arrows when you are writing about a process such as photosynthesis.
- Next annotate the diagram. Annotate means to write the function of each labelled part.

Table 7.3 The role of the medulla

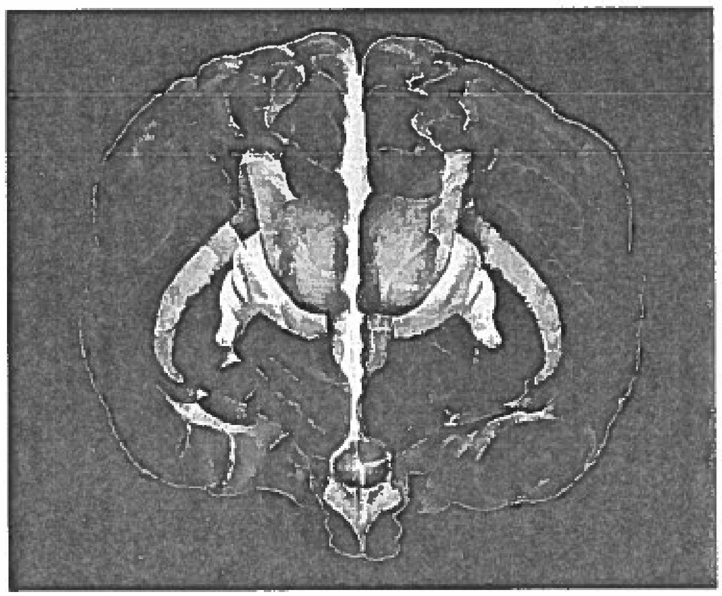
Swallowing	Coordinates muscles of mouth, throat, and larynx
Breathing	Monitors carbon dioxide in the blood. If carbon dioxide is high, your breathing will increase
Heart rate	Speeds up or decreases the rate in response to the autonomic nervous system (see Figure 7.11)

Identifying the role of different brain parts

The study of the complex information processing system that includes the brain and the nervous system is called neuroscience or neurobiology. New technology has provided us with valuable insights into the functions of our brains. Animal experimentation has allowed us to see exactly what causes some of our behaviour. Brain injuries have been studied to show what occurs when parts of the brain are damaged. Brain scans using fMRI have revealed the effects of addictive drugs on the brain. There are published studies of how pain is perceived, and how endorphins act as painkillers.

TOK

New technology to study the human brain has been advancing at a rapid rate. Does this new knowledge of the human brain have intrinsic value or is it a double-edged sword that can be used for good and bad? Just as nuclear physics might be used to develop cheap sources of energy or to make bombs, could human brain research have both good and bad consequences? What are some of the potential benefits of new technology that has been developed to study the human brain? What are some of the potential hazards?



This is a coloured composite three-dimensional functional magnetic resonance imaging (fMRI) and computed tomography (CT) scan of the human brain, seen from the front. The ventricles (pink) circulate the cerebrospinal fluid, which cushions the brain. Beneath the ventricles lie the thalami (orange), and the hypothalamus (green, centre), which controls emotion and body temperature, and releases chemicals that regulate hormone release from the pituitary gland (the round green body at the lower edge).

Brain lesions

One method of studying the brain is to look at people who have had injuries to particular areas of their brain. Lesions in identifiable areas of the brain tell us indirectly about the function of those parts of the brain. Some lesions that have been studied were in either the right or the left half of the brain, and have provided us with information about the differences between the two halves.

The brain is divided into the left and the right hemispheres. These hemispheres are connected by a thick band of axons called the corpus callosum. The two hemispheres do not have exactly the same functions.

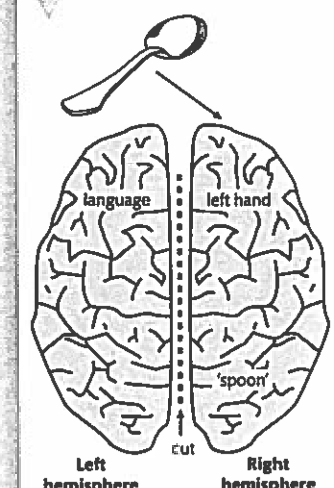
The left hemisphere contains areas important for all forms of communication. Left-hemisphere damage can result from a stroke (broken or blocked blood vessels in the brain). After left-hemisphere damage, patients may have difficulty speaking or doing complicated movements with their hands or arms. Deaf people who have had left-hemisphere damage may no longer be able to use sign language to communicate.

The right hemisphere is not involved in communication, although it does help us to understand words. It specializes in receiving and analysing the information that comes from all of our senses. When people have lesions in the right hemisphere, they have problems identifying faces and locating an object correctly in space. Such a patient might not be able to identify melodies, for example. The right hemisphere helps us understand what we hear and what we see.

Early experiments with brain lesions were done in the mid-1800s with people who had particular injuries. Two neurologists observed that people who had injuries on the left side of the brain had speech and language problems. People who had injuries in the same areas but on the right side of the brain had no language problems. The two areas of the brain important for language are named after these scientists: Pierre Paul Broca and Cark Wernicke. Injury to the Broca's area interferes with the ability to vocalize words; injury to the Wernicke's area affects the ability to put words into sentences. Both areas are on the left side of the brain.

Another series of experiments was carried out in the 1960s. Scientists trying to find out about brain functions became interested in studying a group of patients who had undergone surgery to sever their corpus callosum to relieve symptoms of epilepsy. Experiments were devised to determine how splitting the brain affected these patients. Researchers already knew that input from the right visual field is received by the left hemisphere, and input from the left visual field is received by the right hemisphere.

Figure 7.8 The split-brain experiment with a spoon.



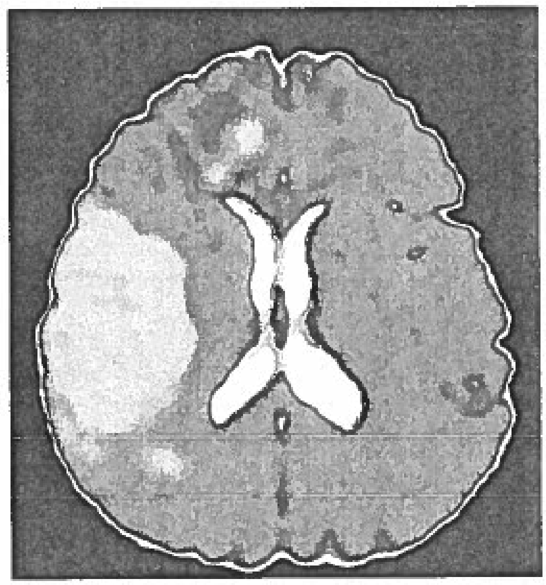
The scientists projected a picture of a spoon onto the right side of a card with a dot in the middle. If a split-brain person is sitting down looking at the dot and a picture of the spoon is flashed up, the visual information about the spoon crosses the optic chiasma and ends up on the left hemisphere. The person has no trouble identifying the spoon and says 'spoon'. (The language centre is in the left hemisphere.)

If the spoon is projected on the left side of the dot, the information goes to the right side of the brain, where there is no language ability (see Figure 7.8). In this case the person will say that he or she has seen nothing. Then the scientists asked the same person to pick up a spoon with his or her left hand. The subject correctly picks up the spoon. The verbal information travels to the right hemisphere, which understands what a 'spoon' is even if the word 'spoon' cannot be verbalized. If that person is then asked what is in his or her hand, he or she will not be able to say 'it is a spoon'. The right hemisphere has little language ability.

Functional magnetic resonance imaging (fMRI)

Functional magnetic resonance imaging (fMRI) uses radio waves and a strong magnetic field, not X-rays. This instrument enables scientists to see the blood flow in the brain as it is occurring. Researchers make movies of what is going on in the brain as a subject performs tasks or is exposed to various stimuli. This method can produce a new image every second. It can determine with some precision when regions of the brain become active and how long they remain active. This means it is possible to determine whether brain activity occurs in the same region or different regions at the same time as a patient responds to experimental conditions. A different tool called a positron emission tomography (PET) scanner is slower but has the advantage of being able to identify the areas of the brain activated by neurotransmitters and drugs. An fMRI is used by doctors to determine:

- a plan for surgery
- treatment for a stroke
- placement of radiation therapy for a brain tumour
- the effects of degenerative brain diseases such as Alzheimer's
- the diagnosis of how a diseased or injured brain is working.



fMRI scan of the brain of a patient after a stroke. The large area of yellow is a result of lack of blood flow to that area of the brain. The blockage of blood flow may be due to a blood clot. Strokes can cause the hemisphere in which they are located to lose function.

Animal experiments

One type of relevant animal experimentation is to expose animal models to addictive substances in controlled situations. Animal models respond in similar ways to humans when addicted. Addicted animals:

- want more and more of the substance
- spend lots of time and energy getting the substance
- keep taking the substance despite adverse conditions
- have withdrawal symptoms upon withdrawal of the substance
- go back to the substance when stressed
- go back to the substance with another exposure to that substance.

To test whether a chemical meets the criteria for an addictive substance, a controlled self-administration experiment is designed and the response of the animal is recorded to see whether it fits the above model for addiction (see Figure 7.9).

1. An animal is trained to press a lever to get a reward.
2. The animal is given an injection of an addictive substance as it pushes the lever.
3. The lever will automatically give the injection if it is pushed by the animal (self-administration).
4. In order for this to be a controlled experiment, two levers must be available, one that gives the substance and one that does not (we want to be sure the animal is not just pushing the lever randomly).

5 If the substance is 'reinforcing', the animal will seek to repeat the experience by pushing that lever much more frequently. This would support the hypothesis that the substance is addictive.

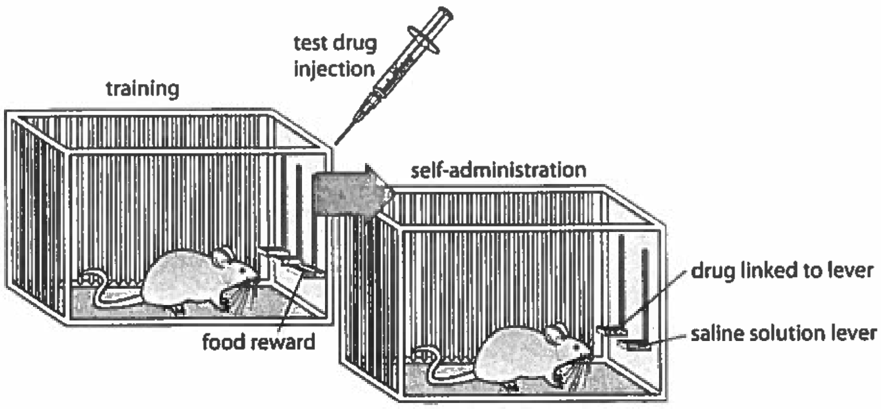


Figure 7.9 A self-administration experiment.

Researchers have recently used a self-administration experiment to support the hypothesis that acetaldehyde, which is a component of tobacco smoke, increases the addiction of adolescents to tobacco (see Figure 7.10).

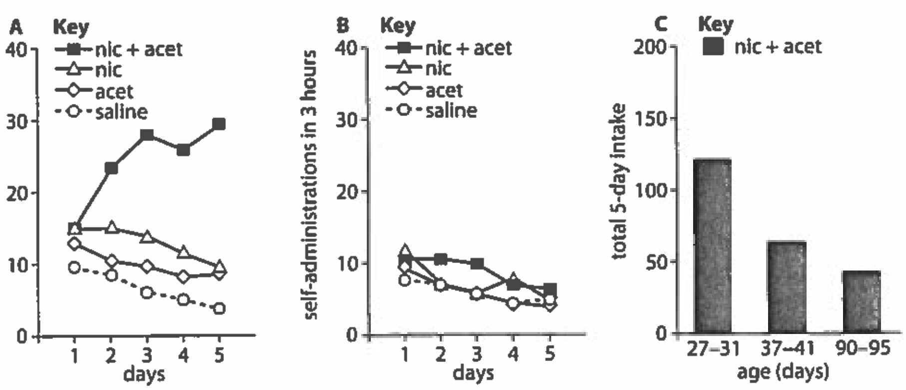


Figure 7.10 Adolescent rat experiments with nicotine and acetaldehyde.
A Adolescent rats (27 days old) self-administered nicotine combined with acetaldehyde with increasing frequency over 5 days, but did not with nicotine alone, acetaldehyde alone, or saline.
B Adult rats (90 days old) did not demonstrate any preference.
C The total 5-day intake of nicotine plus acetaldehyde was greatest for the youngest group of animals. This suggests that vulnerability to tobacco addiction decreases with age.

Animal experiments can shed light on the way that drugs promote abuse and addiction. Yet animal experiments can never replicate the complete picture of human interactions with drugs. Social factors are not considered in these experiments. Thus the results need to be interpreted with caution. Recent advances in technology have enabled researchers to use fMRI to answer questions that previously required an animal model.

TOK

According to Karl Popper, science is based on a series of theories. Scientific beliefs change over time, and it can be argued that a newer theory is closer to the truth than a previous theory. With enough evidence, there may be a paradigm shift as a new theory has more evidence to support it. Currently, the prevailing theory about the cause of Alzheimer's disease is that amyloid plaque accumulates on neurones. Alzheimer's disease results in extreme memory loss and affects millions of people worldwide. New research by Ben Barnes, published in the *Journal of Neuroscience* in 2013, is counter to the prevailing theory about Alzheimer's disease. The problem may not be the accumulation of plaque but an accumulation of a protein called C1q, which builds up on the synapse. Will there be a paradigm shift regarding the cause of Alzheimer's disease?

A report released by the World Health Organization (WHO) claims that neurological disorders, such as Alzheimer's disease, epilepsy, stroke, headache, Parkinson's disease, and multiple sclerosis, affect 1 billion people worldwide.

Autopsy

Autopsy can also be used to determine what brain parts are involved in certain functions. Paul Broca was a French surgeon who discovered the area of the brain involved in language. He autopsied the brain of a deceased patient who had a strange language disorder. The man was able to understand spoken language and could move his mouth and tongue, so he did not have motor impairment. However, he could not express his thoughts by writing or speaking. Following an autopsy of the man's brain, a lesion was discovered in the left inferior frontal cortex located in the left cerebral hemisphere. After studying the brains of eight other patients with similar disorders and finding the same lesions, Broca described this area of the brain in the left hemisphere as the language centre. This specific area in the left hemisphere is now called Broca's area and was the first area of the brain to be associated with a specific function.

Table 7.4 Methods for identifying the roles of different parts of the brain

Method	Results that can be determined
fMRI	Blood flow in the brain to determine whether a patient has had a stroke (blockage of blood flow) Brain tumour Effects of Alzheimer's disease
Brain lesion	Activities that reside in each hemisphere: left is for communication right is for analysis
Autopsy	Learning what areas of the brain control certain functions, e.g. a man who could not express his thoughts in writing and speaking had a lesion in the left cerebral hemisphere
Animal experimentation	Effect of drugs on the animal brain Addiction in the animal

The autonomic nervous system has two divisions

The brain is part of the central nervous system (CNS). The other part of the nervous system is the peripheral nervous system (PNS). The peripheral nervous system is considered to have two parts, the somatic system and the autonomic system (ANS). The somatic system takes sensory information from sensory receptors to the CNS and then sends back motor commands from the CNS to the muscles. The pain reflex arc is part of this system.

The ANS of the PNS is involuntary and regulates the activities of glands, smooth muscle, and the heart. Within the brain the ANS is located in the medulla oblongata. There are also two divisions to the ANS: the sympathetic system and the parasympathetic system.

CNS:

- brain
- spinal cord.

PNS:

- somatic (voluntary), information is received by the senses and messages sent to the skeletal muscles
- autonomic (involuntary), controls cardiac muscle of the heart, smooth muscle, and glands, consisting of two systems that are antagonistic
  - the sympathetic system
  - the parasympathetic system.

Table 7.5 The two PNS systems

Sympathetic system	Parasympathetic system
Important in an emergency	Important in returning to normal
Response is 'fight or flight'	Response is to relax
Neurotransmitter is noradrenaline	Neurotransmitter is acetylcholine
Excitatory	Inhibitory

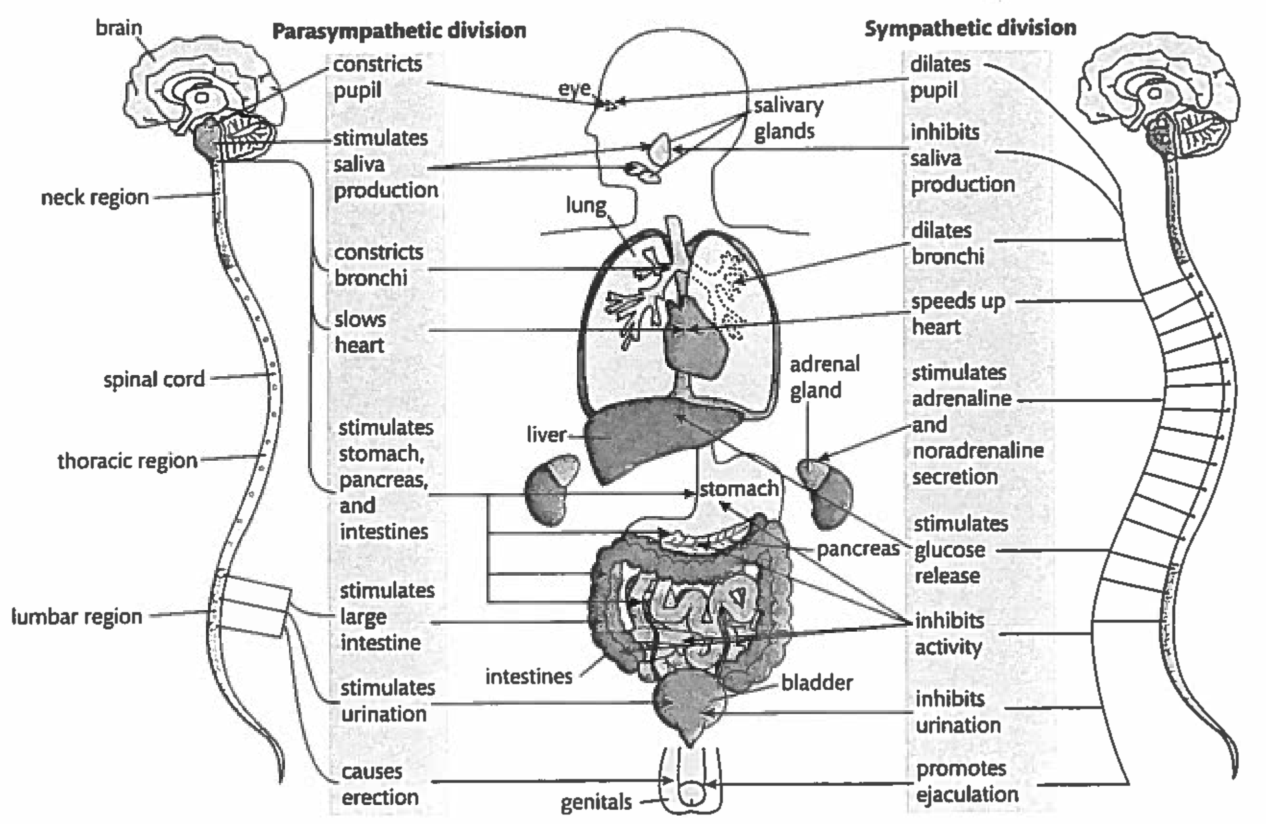
As you can see, the sympathetic and the parasympathetic systems are antagonistic (see Figure 7.11). The sympathetic system is associated with 'fight or flight'. If you are facing an emergency, you need a quick supply of glucose and oxygen. The sympathetic system increases both the heart rate and the stroke volume (the amount of blood pumped by the left ventricle in each contraction) of the heart. It dilates the bronchi to give you more oxygen. It also dilates the pupil of the eye by making the radial muscles of the iris contract. Digestion is not necessary in an emergency, so the flow of blood to the gut is restricted by contraction of the smooth muscle of the blood vessels carrying blood to the digestive system (causing the diameter of the blood vessels to narrow).

If you are not in an emergency situation and are in a relaxed state, the parasympathetic system takes over. Parasympathetic nerves return the system to normal. The pupil of your eye constricts (gets smaller) to protect the retina, caused by contraction of the circular muscles of the iris. The heart rate slows and stroke volume is reduced. Blood flow returns to the digestive system. The smooth muscles of the blood vessels relax and the diameter of the blood vessels becomes wider.

To remember these confusing systems try to make sense of the terms. Peripheral is what is on the outside of the brain and the spinal cord. Somatic has to do with the body, and you know skeletal muscles are voluntary. Autonomic is similar to 'automatic', so you can remember that these functions are not voluntary. Sympathetic is when you are in 'sympathy' with your fear of a lion chasing you. Whereas with the parasympathetic system you are like a 'parrot' sitting up in a tree completely relaxed, because the lion is down on the ground.

If you can take the complex terms of biology and relate them to something else, you will find it easier to remember them.

Figure 7.11 Effects of the autonomic nervous system.



> Make up a story to help you remember the different systems correctly. For example, you would be in 'flight' mode if you were running away from a lion. Your body would be in 'sympathy' with you (sympathetic system). Look at Figure 7.11. Your heart would be racing and your pupils dilated, but the blood flow to your stomach and intestines would be stopped. (You do not need to digest your food as you are running away from a lion.)
>
> However, if you reach the high branches of a tree and are safe, the parasympathetic system would kick in. Look at Figure 7.11 again. Your heart would slow, your bronchi would constrict, and so would your pupils. You do not need to be in 'flight' mode any more.

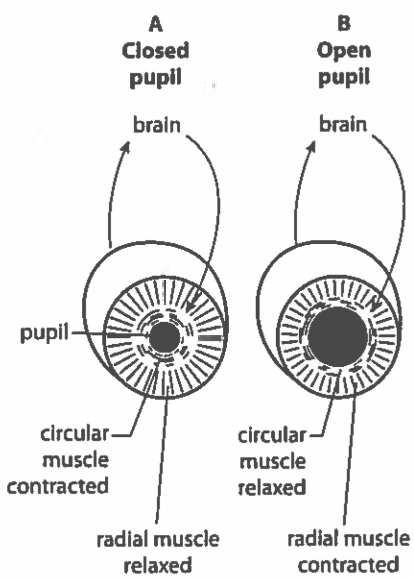


Figure 7.12 The pupil reflex.

The pupil reflex

In order to see the pupil reflex, ask someone to close their eyes and then suddenly open them (see Figure 7.12). You will see the pupil close in response to the sudden input of light as the eyes open. This is as much a reflex as the pain reflex. However, instead of having its connection in the spinal cord, as with the pain reflex, this is a cranial reflex. The sensory and motor neurones connect in the brain rather than the spinal cord.

In the eye, the iris surrounds the opening over the lens that we call the pupil. The iris contains two sets of smooth muscle to open and close the pupil like the aperture on a camera. The pupil closes as a result of a parasympathetic response caused by acetylcholine. If you go to an eye doctor, he or she may dilate your pupils by using a drug called atropine. Atropine stops the action of the neurotransmitter, acetylcholine. Constriction of the pupil happens because of a motor neurone causing the circular muscle to contract and so the radial muscle relaxes.

The pathway of the pupil reflex is shown in Figure 7.13 and described below.

- The optic nerve receives the messages from the retina at the back of the eye. The retina contains photoreceptors that receive the stimulus of light. Photoreceptors synapse with the bipolar neurones and then with the ganglion cells. Nerve fibres of the ganglion cells become the optic nerve.
- The optic nerve connects with the pretectal nucleus of the brainstem (the rectangle in Figure 7.13).
- From the pretectal nucleus, a message is sent to the Edinger–Westphal nucleus (the triangle in Figure 7.13), the axons of which run along the oculomotor nerves back to the eye.
- Oculomotor nerves synapse on the ciliary ganglion (the small circle in Figure 7.13)
- The axons of the ciliary ganglion stimulate the circular muscle of the iris, so it contracts.

Brain death

As a result of recent advances in the treatment of patients, it is possible to artificially maintain the body without the impulses that normally come from the brain. The brainstem controls heart rate, breathing rate, and blood flow to the digestive system. The brain also controls body temperature, blood pressure, and fluid retention. All of these functions can be controlled for a patient without a functioning brain.

You may have heard news reports about patients who are living on life support systems but their brain shows no electrical activity. In some of these cases, family

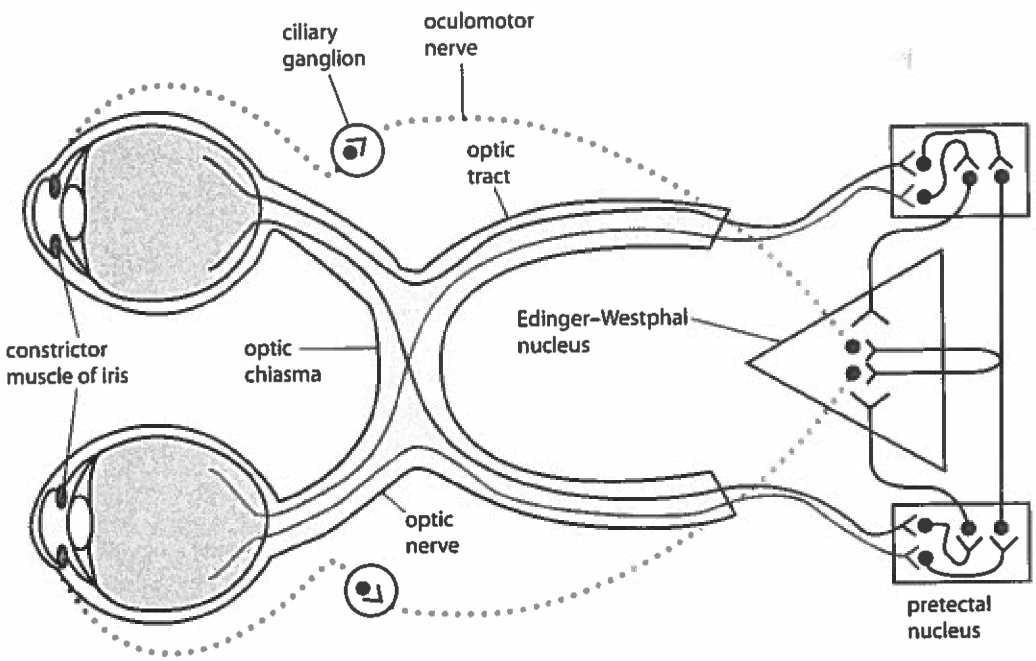


Figure 7.13 Parasympathetic pathways in the pupil reflex.

members may wish to keep the patient on life support because they do not believe that the person is dead. Other family members may believe that the person is dead, because the patient is 'brain dead'. What exactly does brain death mean?

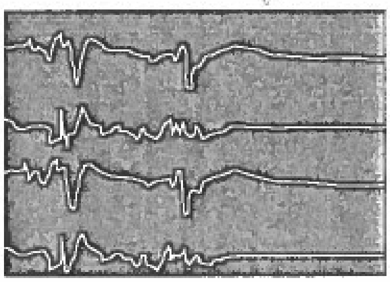
The legal description of brain death is 'that time when a physician(s) has determined that the brain and brainstem have irreversibly lost all neurological function'. But people may still wonder if the patient could be in a coma. Patients in a coma have neurological signs that can be measured. These signs are based on responses to external stimuli. When examining for brain death, a physician must first perform a toxicology test to make sure that the patient is not under the influence of drugs that would slow down neurological reflexes. A diagnosis of brain death includes the following.

- Movement of extremities: if arms and legs are raised and let fall, there must be no other movement or hesitation in the fall.
- Eye movement: eyes must remain fixed, showing a lack of brain-to-motor-nerve reflex (as the head is turned there is no rolling motion of the eyes).
- Corneal reflex: this must be absent (when a cotton swab is dragged over the cornea, the eye does not blink).
- Pupil reflex: this must be absent (pupils do not constrict in response to a very bright light shone into both eyes).
- Gag reflex: this must be absent (the insertion of a small tube into the throat of a comatose patient will cause a gag reflex).
- Respiration (breathing) response: this must be absent (if the patient is removed from a ventilator, he or she does not breathe).

Following assessment by one or more physicians, a patient who shows none of these functions can be pronounced 'brain dead'. If the patient is missing all of the reflex responses and pupil responses, the evidence is clear that the brain will not recover.

However, in a brain-dead person there can still be spinal reflexes. The knee jerk response can still be functional. You may recall that the spinal reflexes do not involve the brain. In some brain-dead patients, a short reflex motion can still be exhibited if the hand or foot is touched in a certain manner.

Figure 7.14 EEG showing activity followed by electrocerebral silence.



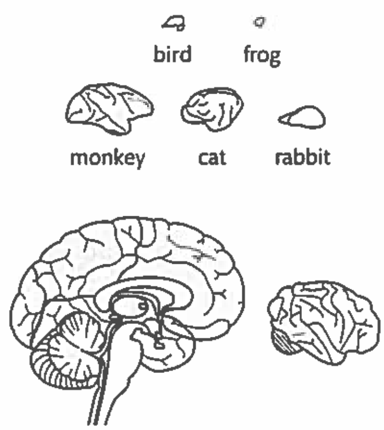
Many doctors order further tests in order to confirm brain death. Two tests commonly used are the electroencephalogram (EEG) and a cerebral blood flow (CBF) study. The EEG measures brain activity in microvolts. It is a very sensitive test. Some electrical activity will be shown on an EEG if a patient is in a deep coma. The lack of activity in a brain-dead patient is called electrocerebral silence (see Figure 7.14).

To measure blood flow to the brain, a radioactive isotope is injected into the bloodstream. A radioactive counter is then placed over the head for about 30 minutes. If no activity is detected, this is conclusive evidence of brain death.

As you can see, the diagnosis of brain death is a very thorough process. At the end of the testing, there can be no doubt about the result. Once this diagnosis has been made, the patient may still be maintained on a ventilator, but a brain-dead person will not recover brain function.

To learn more about reflexes, go to the hotlinks site, search for the title or ISBN, and click on Chapter 7: Section A.2.

Figure 7.15 More intelligent animals have more highly developed cortical surfaces. https://faculty.washington.edu/chudler/brainsize.html



The cerebral cortex

The cerebrum develops from the front part of the neural tube. It is the largest part of the mature brain. As we have seen, the cerebrum consists of two divisions, the left and right cerebral hemispheres. The cerebral hemispheres are covered by a thin layer of grey matter (cells with no myelin sheath around them) called the cerebral cortex. This layer is less than 5 mm thick but contains 75% of the body's neurones. The cortex is where you perform tasks such as:

- reasoning
- language
- complex thought
- visual processing
- motor movement
- remembering
- speech.

The human brain is larger in proportion to its body size than brains of other animals. Orcas (killer whales) may have larger brains by actual volume, but when brain size is compared using a formula that takes body size into account, the human brain is three times as large as that of a chimpanzee and more than twice as large as that of an orca. The expansion of the human brain has come from the growth of the cerebral cortex.

The correlation between body size and brain size

The weight of the brain compared with the weight of the body is called the E:S ratio, where E stands for brain weight and S stands for body weight. Table 7.6 shows the E:S ratio for various species. You can see that humans and mice have the same E:S ratio, while the E:S for small birds is larger than that for humans. Should we therefore conclude that small birds, whose brains are comparatively larger in relation to their size compared with larger animals, are more intelligent than humans? You can see that the brain weight of a vertebrate does not appear to increase linearly with body weight. However, the trend seems to be that the larger an animal gets, the smaller its brain to body ratio. Small mice have a relatively large brain. Large elephants have a relatively small brain.

To improve on the simple ratio method, an equation was developed where E = weight of the brain, S = weight of the body, C = a constant, and r = an exponential constant. Using the formula E = CSr, we can establish the relative capacity of brains of different species with different body weights.

When a value of C can be established for each species, then we can find the EQ or encephalization quotient: EQ = C/average mammalian value. For example, if the EQ of a certain species is 3.0 then the species has a value of C three times as high as a mammal of comparable weight with average encephalization (the ratio between actual brain size and predicted brain mass for an animal of a given size).

Look at the chart of EQ quotients (Table 7.7). A dolphin has an EQ of 5.31, which shows that it is twice as encephalized as a chimpanzee, which has an EQ of only 2.49.

Table 7.6 E:S correlation between the weight of the brain and the weight of the body for different animals
http://en.wikipedia.org/wiki/Brain-to-body_mass_ratio

Species	Simple brain-to-body ratio (E:S)
Small ants	1:7
Small birds	1:14
Human	1:40
Mouse	1:40
Cat	1:110
Dog	1:125
Squirrel	1:15
Frog	1:172
Lion	1:550
Elephant	1:560
Horse	1:600
Shark	1:2496
Hippopotamus	1:2789

Table 7.7 Encephalization quotient (EQ) data
http://serendip.brynmawr.edu/bb/kinser/Int3.html

Species	EQ	Species	EQ
Man	7.44	Cat	1.00
Dolphin	5.31	Horse	0.86
Chimpanzee	2.49	Sheep	0.81
Rhesus monkey	2.09	Mouse	0.50
Elephant	1.87	Rat	0.40
Whale	1.76	Rabbit	0.40
Dog	1.17		

CHALLENGE YOURSELF

We can agree that if the brain weight is large relative to the body (EQ), the animals may be able to accomplish more complex tasks. However, other factors may also be involved. See if you can answer the following questions using the EQ values shown in Table 7.7.

3 Can you see which four animals have diets of meat or fish?

4 Suggest why this diet is beneficial to the species.

5 Which three animals have a plant and insect diet?

6 Why is this diet not as beneficial to a species?

7 Can you think of any animal behaviour that would place a species high on the encephalization scale?

8 Why are rat and rabbit at the bottom in comparison with the other species?

9 Can you guess the name of an invertebrate animal that has a high EQ?

The enlargement of the cerebral cortex

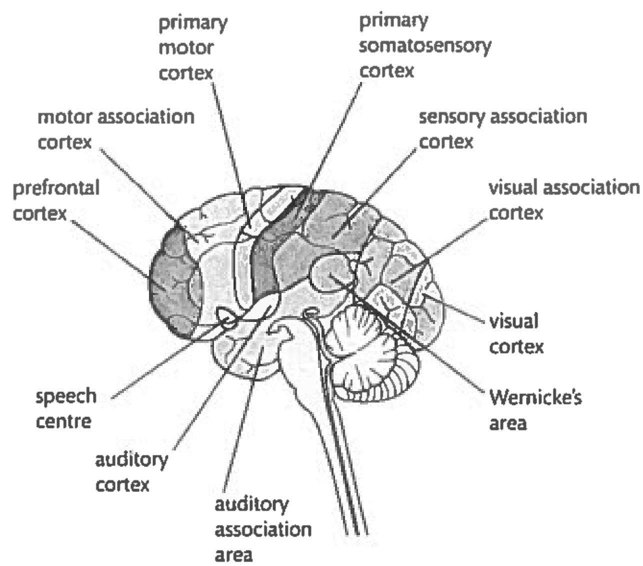


Figure 7.16 Functional divisions of the cerebral cortex. https://faculty.washington.edu/chudler/functional.html

Greater cognitive ability and more advanced behaviour are associated with an increase in size of the cerebral cortex. When we compare human brains with those of other animals, the biggest difference appears to be in the surface area of the cerebral hemispheres. In a mouse, for example, the surface of the cerebral cortex is smooth, while in a dog it is very convoluted. When we study monkeys and apes, even more folds are found in their cortex. In order for the brain to fit into a skull that is actually in proportion to the body, the brain has to fold in on itself. An increased surface area is needed for more complex behaviours, but it still has to fit into the limited space of a skull. One way to have more working surface is to add folds to the surface. If you scrunch up a sheet of A4 paper, it has the same surface area but can take up less space than a flat piece of A4 paper. As species evolved to be able to do more complex behaviours, they had to develop more working area for their brain. The more folding, the more surface area there can be. In this way a larger surface area of cerebral cortex can be contained in a limited space.

A 6-month-old foetus has a completely smooth cerebral cortex. By birth its brain has become the walnut-like structure we would expect to see. The folding of the cerebral cortex during development of the human embryo takes place during the last 3 months of development.

Functions of the cerebral cortex

The extensive folding of the cerebral cortex and the large numbers of neurones present in the cortex are evidence of the importance of this brain part. The higher order functions performed by the cerebral cortex are shown in Table 7.8.

Table 7.8 Functional areas of the cerebral cortex

Part	Function
Prefrontal cortex	Organizes thoughts, solves problems, and formats strategies
Motor association cortex	Coordinates movement
Primary motor cortex	Plans and executes movements
Primary somatosensory cortex	Processes information related to touch
Sensory association cortex	Processes sensory information of perceptions or multisensory information
Visual association area	Processes visual information
Visual cortex	Recognizes visual stimuli
Wernicke's area	Understands written and spoken language
Auditory association area	Processes auditory information
Auditory cortex	Detects sound quality such as loudness or tone
Broca's area	Produces speech and language

The visual cortex, Broca's area, and nucleus accumbens

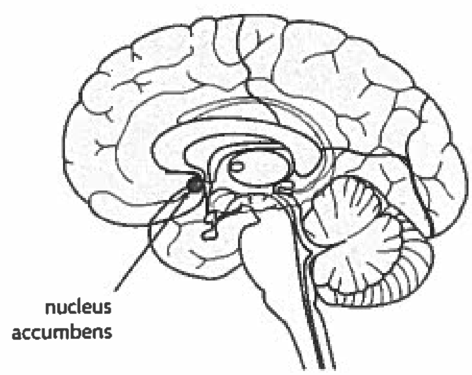


Figure 7.17 Nucleus accumbens is associated with the rewards circuit in the brain.

Broca's area is one of two parts of the cerebral cortex linked to speech and language (the other is Wernicke's area). Broca's area is labelled 'speech centre' in Figure 7.16. When a patient has a brain injury causing lack of language production, it is called Broca's aphasia. Paul Broca discovered the language function of this area.

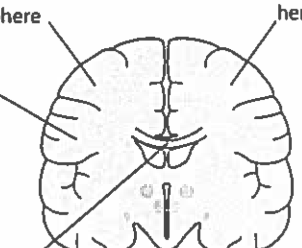
The nucleus accumbens (see Figure 7.17) is associated with the reward circuit in the brain. It responds chiefly to two neurotransmitters: dopamine and serotonin. Dopamine promotes desire, while serotonin inhibits desire. The activation of dopamine in the nucleus accumbens is associated with the anticipation of a reward. Drugs such as cocaine and nicotine also increase dopamine production in the nucleus accumbens. The reward of increased dopamine can result in addiction.

The visual cortex is the part of the brain that receives information from the cells in the retina of the eye. The visual cortex (see Figure 7.16) is one of many brain centres that cooperate to produce vision.

The left cerebral hemisphere receives sensory information from the right side of the body, and vice versa

The cerebral cortex is the thin layer on the surface of the left and right cerebral hemispheres and is responsible for all higher order functions. The cerebral cortex is made up of unmyelinated neurones and is called grey matter. The two cerebral hemispheres are connected by a thick band of tissue called the corpus callosum, through which communication takes place between the right and left sides of the brain. The corpus callosum is made up of myelinated neurones and is called white matter. Each cerebral hemisphere is responsible for one half of the body. The left cerebral hemisphere receives sensory input from sensory receptors on the right side of the body and the right side of the visual field in both eyes, and vice versa for the right hemisphere.

Figure 7.18 The corpus callosum connects the two cerebral hemispheres.



Each side of the cortex is divided into further sections depending on the activity that it performs. For example, look at Figure 7.16 and you can see the primary somatosensory cortex and the motor cortex. The primary somatosensory cortex is the main area for receiving the sense of touch. Sensory input from the right hand is sent to the left primary somatosensory cortex, and vice versa.

The neural pathways for vision travel to the primary visual cortex. As you might expect, the right side of the brain receives information from the left visual field, and the left side of the brain receives information from the

NATURE OF SCIENCE

Look at the diagram of a cross-sectional map of the primary somatosensory cortex (Figure 7.19).

The relative space that the human body parts occupy in the sensory cortex can be illustrated by a 'cartoon-like' homunculus (man). In this picture you can see the homunculus, a distorted model that reflects the relative space that human body parts occupy in each cortex. Notice that the head occupies a large area but the hips and legs only occupy a small area. Sensory information from the head is much more important and has more brain space available to it than sensory information from for hip or leg. What seems to be more important in the motor cortex, the head or the knee?

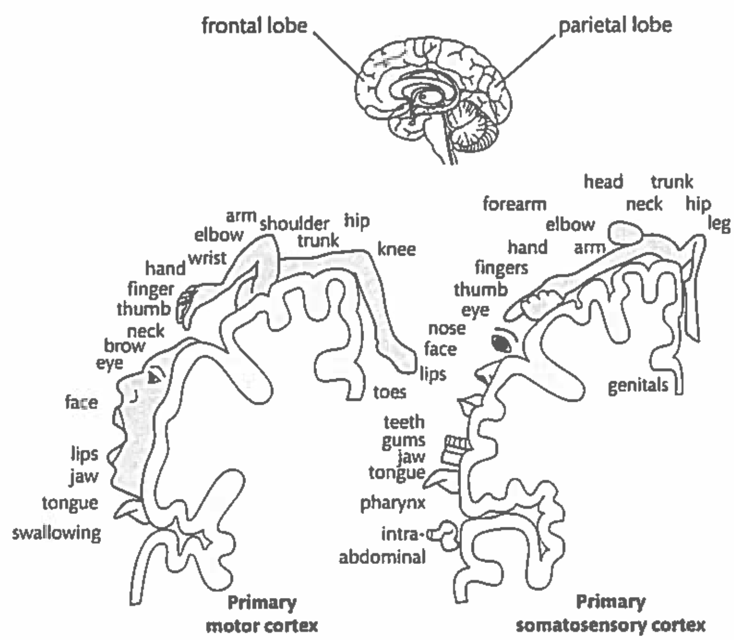


Figure 7.19 This homunculus cartoon shows the relative importance of areas of the body in the primary motor cortex and the primary somatosensory cortex.

right visual field. Looking at Figure 7.20, you can see that the optic nerves from the left field, shown in blue, can cross over at the optic chiasm so that the information from left field of view is received by right side of the brain, and vice versa.

Practise drawing diagrams of the neural pathway for vision until you understand it thoroughly.

The left cerebral hemisphere controls muscle contraction in the right side of the body, and vice versa

Now let's look at the motor cortex. The motor cortex controls voluntary movements. As you can guess, the motor cortex in the right cerebral hemisphere controls movement on the left side of the body, and vice versa. This can be very obvious in patients who have had a stroke.

When a person has a stroke, it is localized and often occurs in either the left or right cerebral hemisphere. A stroke is caused by a blocked or ruptured blood vessel. This interrupts oxygen flow to the brain cells. If a motor area of the cerebral hemisphere on the left side of the brain is affected, then paralysis will be seen in the right arm and right leg. The location of the paralysis tells the doctor which side of the brain has been injured as a result of loss of oxygen. Fortunately, because the brain has plasticity, other parts of the brain may take over during rehabilitation and facilitate the return of full motion.

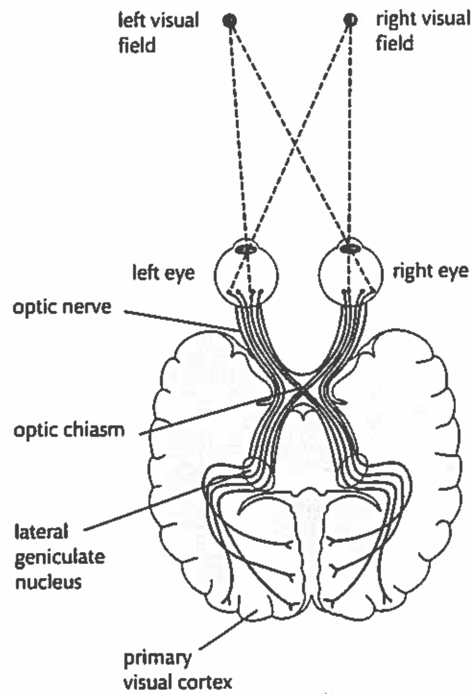


Figure 7.20 Two eyes connected to the brain by optic nerves. The left visual field is giving information to the right side of the primary visual cortex (note the blue lines). The right visual field is giving information to the left side of the primary visual cortex (note the red lines).

Brain metabolism requires large energy inputs

Neurones have a high energy need because they are always in a state of high metabolic activity. As you will recall, metabolism consists of all the chemical activities performed by a cell. Neurones perform many tasks that are similar to other cells, such as repairing or rebuilding their structural components. However, the chemical signals that are responsible for the communication between neurones consume half of all the energy used by the brain. This is why a brain cell needs twice the amount of energy as any other cell in a body.

Glucose is the primary energy source that fuels the metabolism of neurones in the human brain. Neurones cannot store glucose, so the blood must deliver a constant supply. Because of its high rate of metabolism, glucose is used up rapidly by neurones during mental activity. In an experiment on rats, scientists at the University of Illinois College of Medicine found that young rats have a good supply of glucose to the area of the brain involved in learning and memory, while older rats to do not have such a good supply. The supply of glucose for older rats runs out much more quickly. When glucose runs out, the behaviour of the older rats indicates that there is a large deficit in learning.

The hand area of the primary motor cortex is known to be larger among professional pianists than among amateur pianists. Peter L. Strick, from the Department of Neurobiology, Pitt School of Medicine, suggests that this indicates that extensive practice induces changes in the primary motor cortex.

Blood sugar (glucose) is supplied by the food that you eat. High-quality carbohydrates, such as fruits, vegetables, legumes, grains, and dairy, are the best source of glucose. These foods provide the brain with a supply of glucose that lasts for hours. Food such as sugar snacks and drinks provide glucose quickly, but the supply does not last as long and can result in low brain activity. It has been seen in animal models that sustained levels of glucose in the brain are beneficial for learning.

Worked example

Why is it better to eat an apple, rather than candy, when you are studying for a test?

Solution

Sugary snacks can give you quick glucose, but you need some more long-lasting brain energy when studying for a test. The candy will give you quick energy, but soon after you might get really sleepy. That would be the 'sugar' low that can occur after a 'sugar' high. The apple contains sugars but it must be digested, and its sugars are absorbed more slowly into the blood.

Angelman's syndrome is diagnosed from well-recognized abnormal patterns on an electroencephalogram (EEG). Symptoms include developmental delay of 6–12 months in babies, in addition to facial abnormalities and seizures. Angelman's syndrome is a genetically inherited disorder that primarily affects the nervous system.

Section summary

- Different parts of the human brain have different functions. The brain regulates unconscious activities such as heart rate, blood pressure, breathing, balance, muscle coordination, and voluntary movement. It also deals with emotion, speech, and problem solving, as well as allowing you to think and dream.
- Scientists have learned about the function of the parts of the brain by using brain scans such as functional magnetic resonance imaging (fMRI), by studying brain injuries, by animal experimentation, and by performing autopsies.
- Divisions of the nervous system include the central nervous system (CNS, the brain and spinal cord) and the peripheral nervous system (PNS).
- The two parts of the PNS are the sympathetic system and the parasympathetic system. The sympathetic system responds to an emergency and the parasympathetic system returns the system to normal. The pupil reflex is an example of how these two systems work. The pupil dilates in an emergency and constricts as the system returns to normal.
- Brain death is when the brain and brainstem have irreversibly lost all neurological function.
- The human brain is larger in proportion to its body than the brains of other animals. The measurement that shows the relationship of brain size to body size is the encephalization quotient.
- When comparing the brain to body relationship, the biggest difference is the large size of the human cerebral cortex. Extensive folding of the cerebral cortex allows a large number of neurones to be present.
- Certain areas of the cerebral hemisphere have specific functions. The cerebral hemisphere is the area of integration for complex functions such as learning, memory, and emotions.

Exercises

5 Draw and annotate a diagram of the human brain.

6 Describe how an fMRI is used to identify the role of different brain parts.

7 State the specific function of each of the following: Broca's area; nucleus accumbens; visual cortex.

8 Explain how folding has allowed the cerebral cortex to become more highly developed in humans than in other animals.

9 Explain why brain metabolism requires a large input of energy.

A.3 Perception of stimuli

Understandings:

- Receptors detect changes in the environment.
- Rods and cones are photoreceptors located in the retina.
- Rods and cones differ in their sensitivities to light intensities and wavelengths.
- Bipolar cells send the impulses from the rods and cones to ganglion cells.
- Ganglion cells send messages to the brain via the optic nerve.
- The information from the right field of vision from both eyes is sent to the left part of the visual cortex and vice versa.
- Structures in the middle ear transmit and amplify sound.
- Sensory hairs of the cochlea detect sounds of specific wavelengths.
- Impulses caused by sound perception are transmitted to the brain via the auditory nerve.
- Hairs in the semicircular canals detect movement of the head.

Applications and skills:

- Application: Red-green colour blindness as a variant of normal trichromatic vision.
- Application: Detection of chemicals in the air by the many different olfactory receptors.
- Application: Use of cochlear implants by deaf patients.
- Skill: Labelling a diagram of the structure of the human eye.
- Skill: Annotation of a diagram of the retina to show the cell types and the direction in which light moves.
- Skill: Labelling a diagram of the structure of the human ear.

Guidance

- *Humans' sensory receptors should include mechanoreceptors, chemoreceptors, thermoreceptors, and photoreceptors.*
- *Diagram of human eye should include the sclera, cornea, conjunctiva, eyelid, choroid, aqueous humour, pupil, lens, iris, vitreous humour, retina, fovea, optic nerve, and blind spot.*
- *Diagram of retina should include rod and cone cells, biopolar neurones, and ganglion cells.*
- *Diagram of ear should include pinna, eardrum, bones of the middle ear, oval window, round window, semicircular canals, auditory nerve, and cochlea.*

NATURE OF SCIENCE

Understanding of the underlying science is the basis for technological developments: the discovery that electrical stimulation in the auditory system can create a perception of sound resulted in the development of electrical hearing aids and ultimately cochlear implants.

Sensory receptors and diversity of stimuli

Certain foods can make you feel comforted. Seeing a familiar face in a crowd can make you feel at ease. Listening to your favourite music can make you feel happy. We have learned to link certain tastes, sights, and sounds with emotions. Sensory cells send messages to certain parts of the brain that control emotion and memory.

Taste and sound are not just for pleasure. They also protect us. We remember the taste of mouldy food. We move out of the way when we hear a car coming. Many lives have been saved by smelling smoke.

Sense organs are the windows to the brain. They keep the brain aware of what is going on in the outside world. When stimulated, the sense organs send a message to the central nervous system. The nerve impulses arriving at the brain result in sensation. We actually see, smell, taste, and feel with our brain rather than our sense organs.

We link certain tastes to emotion and memory. Some foods make us remember our childhood.

Receptors detect changes in the environment

Mechanoreceptors

Mechanoreceptors are stimulated by a mechanical force or some type of pressure. The sense of touch is caused by pressure receptors that are sensitive to strong or light pressure. In our arteries, pressure receptors can detect a change in blood pressure. In our lungs, stretch receptors respond to the degree of lung inflation. We can tell the position of our arms and legs by the use of proprioceptors found in muscle fibres, tendons, joints, and ligaments. These receptors help us maintain posture and balance. In our inner ear, there are pressure receptors sensitive to the waves of fluid moving over them. This gives us information about our equilibrium.

Chemoreceptors

Chemoreceptors respond to chemical substances. Using this type of receptor, we can taste and smell. They also give us information about our internal body environment. Chemoreceptors in some blood vessels monitor pH changes. Changes in pH signal the body to adjust the breathing rate. Pain receptors are a type of chemoreceptor that respond to chemicals released by damaged tissues. Pain protects us from danger. The pain reflex makes us pull away, for example, from a hot object. Olfactory receptors respond to smell.

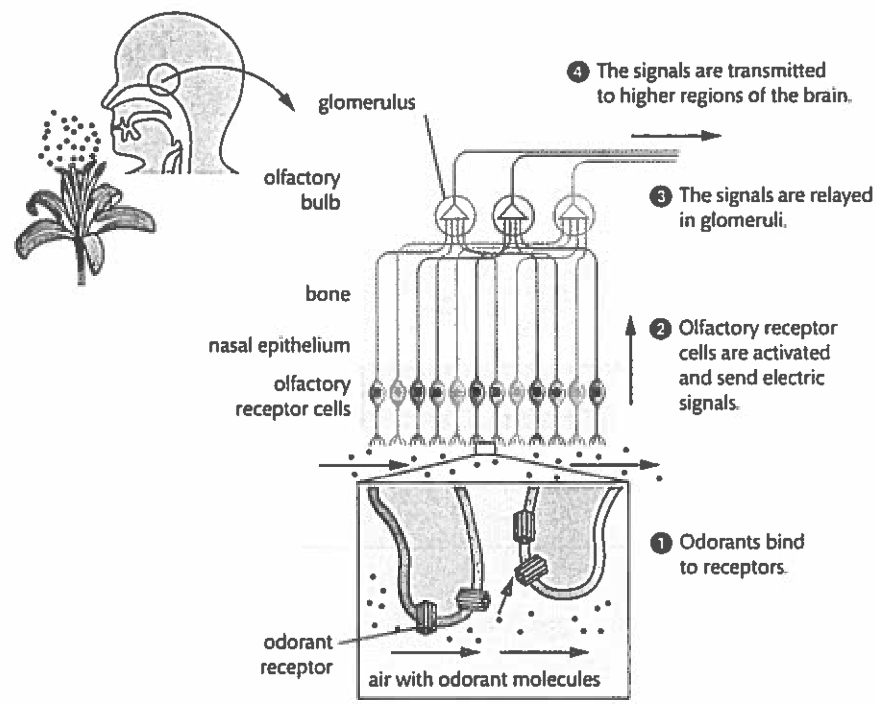


Figure 7.21 How receptors function in the olfactory system.

How does smell work? Everything you can smell, like bread baking, onions, coffee, anything good or bad, is releasing volatile molecules that diffuse into the air. These molecules then reach the olfactory receptors in your nose: 10 000 different smells can be detected by these receptors in humans.

At the top of your nasal passage is a patch of specialized neurones that contain the olfactory receptors. A given molecule may stimulate more than one receptor. The combination of several receptors is registered by the brain as a certain smell. Scientists have hypothesized that each of our hundreds of olfactory receptors is encoded for by a specific gene. Each specific gene recognizes a different smell. If your DNA does not have a certain gene, you may be unable to smell a certain smell. For example, some people cannot smell digested asparagus but others can.

Chemoreceptors are very important in the entire animal kingdom. Chemoreception is the oldest and most universal sense. It probably guides the behaviour of animals more than any other sense. For example, it allows bees to have social organization regulated by chemical molecules called pheromones. Vertebrates also respond to pheromones. Sex pheromones in vertebrates are chemicals that help individuals of the same species find each other and mate. Some animals find their prey by tracking chemicals released by the prey into the environment. For example, when a blue crab is hunting a clam, it finds the clam by following the chemical released into the river by the clam.

TOK

We depend on more than our senses to know the biological world. To what extent are we dependent on technology for our knowledge of biology? As an example, we use molecular tools to read the basic instructions of life one letter at a time as we decode the human genome. What other ways can you think of in which we use technology to know the biological world?

Thermoreceptors

Thermoreceptors respond to a change in temperature. Warmth receptors respond when the temperature rises; cold receptors respond when the temperature drops. Human thermoreceptors are located in the skin.

Photoreceptors

Photoreceptors respond to light energy; they are found in our eyes. Our eyes are sensitive to light and give us vision. Rod cells in our eyes respond to dim light, resulting in black and white vision; cone cells respond to bright light, giving us colour vision.

Vision 2020 is a joint initiative of the World Health Organization and the International Agency for the Prevention of Blindness, whose goal is to eliminate avoidable blindness worldwide by the year 2020. Vision 2020 wants to give everyone in the world the right to sight.

Table 7.9 A summary of major sensory receptors

Sensory receptor type	Example/location	Function
Mechanoreceptors	Arteries, lungs, tips of fingers	Generate nerve impulses when stimulated, may indicate touch, pressure, stretch, balance
Chemoreceptors	Nose, mouth, blood vessels	Respond to chemicals in solution, e.g. taste, smell, and blood chemistry
Thermoreceptors	Skin, lining of mouth	Detect hot and cold temperatures
Photoreceptors	Retina of the eyes (rods and cones)	Respond to light energy

The structure and function of the human eye

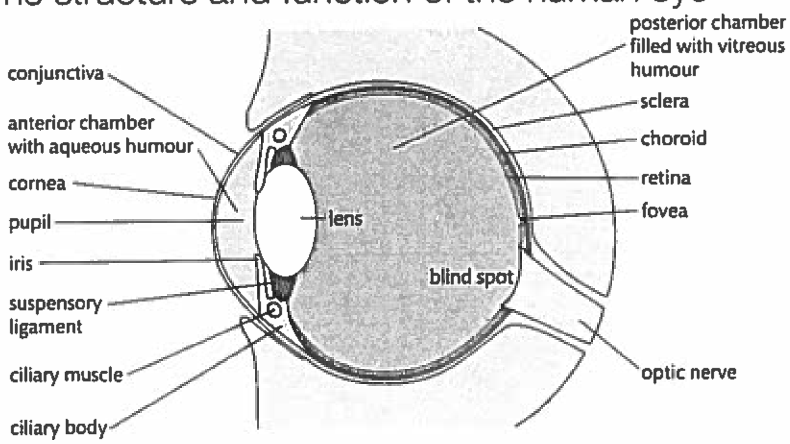


Figure 7.22 The human eye.

CHALLENGE YOURSELF

10 Many pictures are available online that you can use to practise labelling the parts of the eye. Print out a picture with missing labels and practise labelling the eye until you are sure you have learned all the parts perfectly. Use the hotlinks at the end of this section to find a diagram you can label as an interactive task. Next learn the function by covering up one side of Table 7.10 with a piece of paper and trying to recreate it.

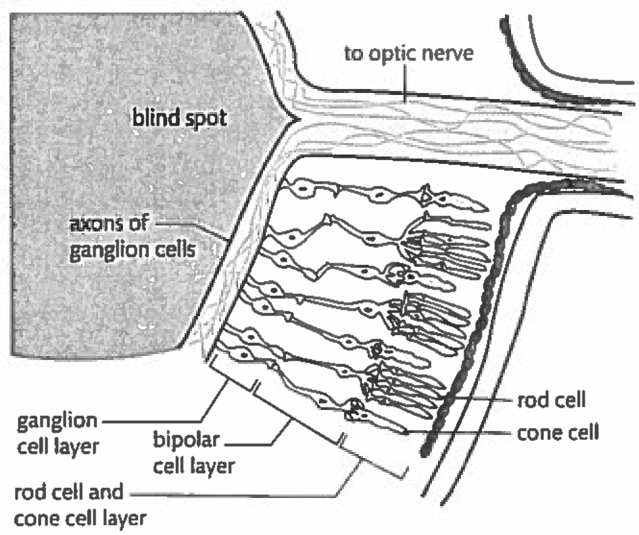


Figure 7.23 Structure of the retina.

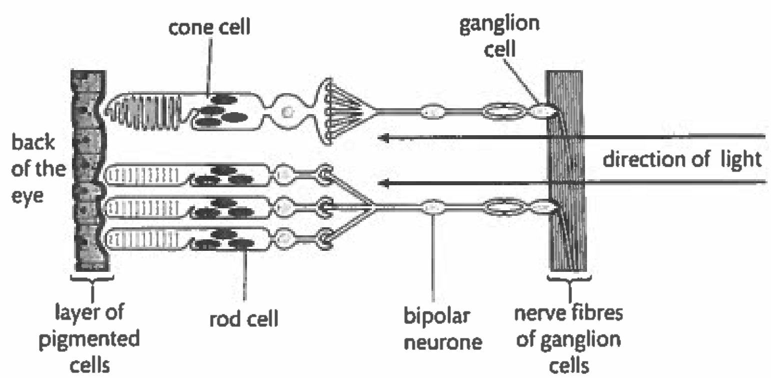


Figure 7.24 Structure and function of the retina.

Table 7.10 summarizes the functions of the various parts of the eye.

Table 7.10 The functions of various parts of the eye

Part	Function
Iris	Regulates the size of the pupil
Pupil	Admits light
Retina	Contains receptors for vision
Aqueous humour	Transmits light rays and supports the eyeball
Vitreous humour	Transmits light rays and supports the eyeball
Rods	Allow black and white vision in dim light

Part	Function
Cones	Allow colour vision in bright light
Fovea	An area of densely packed cone cells where vision is most acute
Lens	Focuses the light rays
Sclera	Protects and supports the eyeball
Cornea	Focusing begins here
Choroid	Absorbs stray light
Conjunctiva	Covers the sclera and cornea and keeps the eye moist
Optic nerve	Transmits impulses to the brain
Eye lid	Protects the eye

The retina

Vision begins when light enters the eye and is focused on the photoreceptor cells of the retina (see Figure 7.23). The photoreceptor cells are the rods and the cones. Notice in Figure 7.24 that both the rods and cones synapse with their own bipolar neurones. Each bipolar neurone synapses with a ganglion cell. The axons of the ganglion cells make up the optic nerve, which carries the message of vision to the brain.

The following bullet points would be suitable for annotating a diagram of the retina.

- Rod cells are photoreceptor cells that are very sensitive to light. They receive the stimulus of light, even very dim light, and synapse with a bipolar neurone.
- Cone cells are photoreceptor cells that are activated by bright light. They receive the stimulus of bright light and synapse with a bipolar neurone.
- Bipolar neurones are cells in the retina that carry impulses from a rod or a cone cell to a ganglion cell of the optic nerve. They are called bipolar because they each have two processes extending from the cell body.
- Ganglion cells synapse with the bipolar neurones and send the impulses to the brain via the optic nerve.

Rods and cones

Table 7.11 provides a comparison of rods and cones.

Table 7.11 Rods and cones

Rods	Cones
These cells are more sensitive to light and function well in dim light	These cells are less sensitive to light and function well in bright light
Only one type of rod is found in the retina. It can absorb all wavelengths of visible light	Three types of cone are found in the retina. One type is sensitive to red light, one type to blue light, and one type to green light
The impulses from a group of rod cells pass to a single nerve fibre in the optic nerve (see Figure 7.24)	The impulse from a single cone cell passes to a single nerve fibre in the optic nerve (see Figure 7.24)

CHALLENGE YOURSELF

11 The next challenge is to learn the parts of the retina using Figure 7.24. The best way to learn this picture is to draw it and label the parts. Be accurate. Notice that the cone cell has only one part, while the rod cell has three. Make sure you understand where the back of the eye is, and the direction from which the light is coming. You can use Figures 7.23 and 7.24 so that you can really understand what is happening. To test yourself another way, try to explain the retina to someone else using the picture.

The steps of the vision pathway in the retina are as follows.

- **Rods and cones receive the light stimulus.**
- **Rods and cones synapse with a bipolar neurone.**
- **The bipolar neurone carries the impulse to the ganglion cell.**
- **The ganglion cell is located in the optic nerve.**
- **The optic nerve carries the impulse to the brain.**

To complete a test for colour blindness, go to the hotlinks site, search for the title or ISBN, and click on Chapter 7: Section A.3.

Red–green colour blindness

Normal vision uses the three classes of cones, red, green, and blue, and is called trichromatic vision. Some individuals are dichromatic and have red–green colour vision defects; dichromatic vision is a variant of trichromatic vision. Red–green defects are inherited as a sex-linked trait: sons can inherit the defect from their mother. It is very rare for females to have this trait. Dichromatic vision can be caused by the presence of blue and green cones with no functional red cones (red-blindness), or by the presence of blue and red cones with no green cones (green-blindness). Dichromats see the world differently depending on the variation they have inherited. Many websites have tests for colour blindness.

Information from the right field of vision from both eyes is sent to the left part of the visual cortex, and vice versa

Review the information in Section A.2 on the human brain and the visual cortex.

The structure of the ear

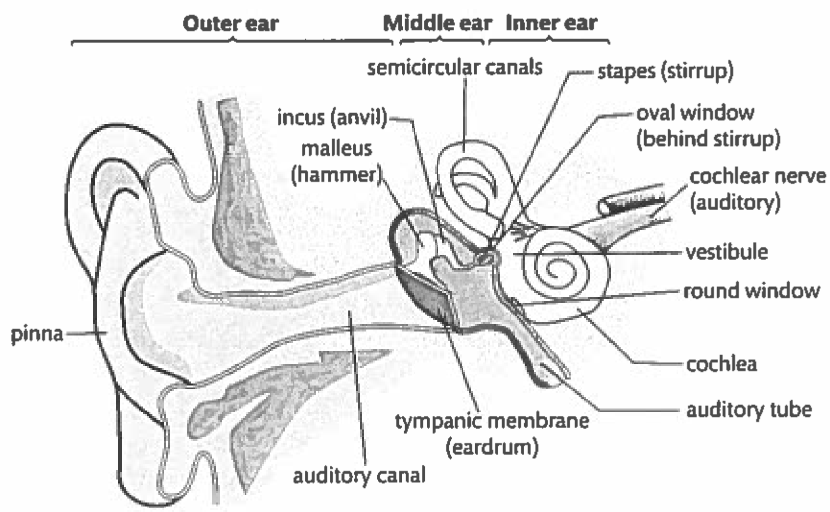


Figure 7.25 Anatomy of the human ear.

How sound is perceived by the ear

Sound waves are successive vibrations of air molecules caught by the outer ear. When they travel down the auditory canal, they cause the eardrum (tympanic membrane) to move back and forth slightly.

Structures in the middle ear transmit and amplify sound

- The bones of the middle ear, the malleus, incus, and stapes, receive vibrations from the tympanic membrane and multiply them approximately 20 times.
- The stapes strikes the oval window, causing it to vibrate.
- This vibration is passed to the fluid in the cochlea.
- The fluid in the cochlea causes special cells, called hair cells, to vibrate.
- The hair cells, which are mechanoreceptors, release a chemical neurotransmitter across a synapse to the sensory neurone of the auditory nerve.
- Vibrations are transformed into nerve impulses.

- The chemical message stimulates the sensory neurone.
- Impulses caused by sound perception are transmitted to the brain by the auditory nerve.
- The round window releases pressure so fluid in the cochlea can vibrate.

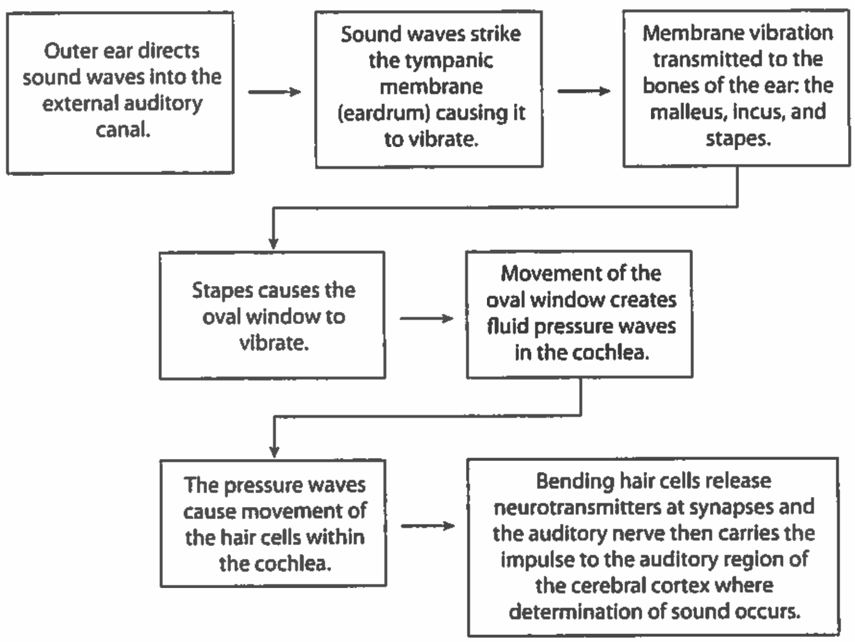


Figure 7.26 The physiology of hearing.

CHALLENGE YOURSELF

12 Here is another opportunity to learn the parts of one of your receptors, the ear. Again find a picture online, print it out, and label it. Label the parts from memory and then begin to learn the bullet points given above in order. Do you have a younger brother or sister who might be fascinated by you telling them the story of how we hear?

Sensory hairs of the cochlea detect sounds of specific length

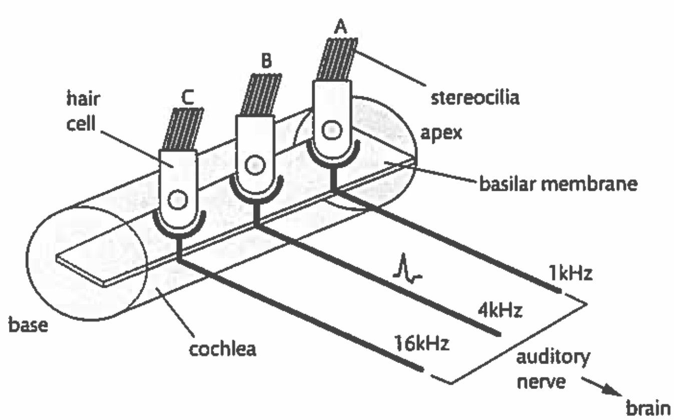


Figure 7.27 The stereocilia in the cochlea detect sounds of a specific wavelength. Hz measures the frequency of those sound waves. Hz is the SI symbol for hertz. A kHz is 1000 cycles per second of waves. Human hearing range is between 20 and 20 000 Hz.

The hair cells of the cochlea have stereocilia that stick out of the hair cells and detect sounds of a specific wavelength. As the stereocilia on the hair cells bend back and

According to the *American Journal of Industrialized Medicine*, excessive noise is a global occupational health hazard resulting in noise-induced hearing loss (NIHL). Adult-onset hearing loss is the 15th most serious world heath problem.

The cochlea has more than 32 000 hair cells.

forth, an internal change in the hair cell itself is created. This change produces an electrical impulse that is carried to the auditory nerve.

Short, high-frequency waves produce high-pitched sounds, while long, low-frequency waves produce low-pitched sounds. The sound, which is sensed by the brain, is processed in the auditory area of the cerebral cortex. Hearing varies between people and changes with age. Hearing can also be affected by high-frequency noise. Listening to high-frequency sound for too long can damage the hair cells in the cochlea, and cochlear hair cells do not grow back. That is why many musicians wear protective ear devices when playing in concerts.

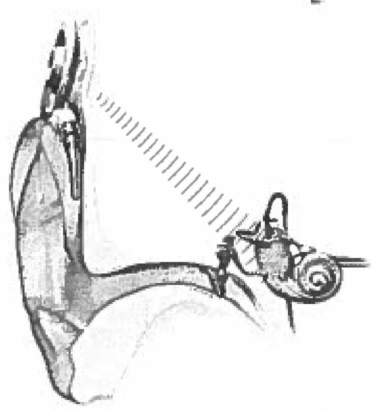
Here are some suggestions from a health professional on how to prevent hearing loss in teenagers.

You can enjoy listening to music yet avoiding harmful listening habits that can lead to permanent hearing loss, by following these steps.

- Switch to headphones: headphones isolate the background noise, so that you can hear the music with less increase in volume.
- Anything higher than 85 dB can cause damage.
- Listening for extended periods of time can impair hearing. Take breaks.
- Try the 60/60 rule: never turn your volume past 60% and only insert earphones for a maximum of 60 minutes per day.

Hair cells in the semicircular canals detect movement of the head

We have three semicircular canals in each inner ear. These semicircular canals control our equilibrium, and give our brain a three-dimensional report of our position. The canals contain fluid and hair cells. Movement of the fluid over the hair cells detects rotational movement of the head. The hair cells are sensory receptors that send messages to the vestibular nerve. This information, which is relayed to the brain, tells us our position. Are we upside down or falling backwards? We can maintain our balance in precarious positions because of the accuracy of the hair cells in the semicircular canals of our ears.



Cochlear implant.

Use of cochlear implants in deaf patients

Cochlear implants are a product of medical technology that has improved the lives of people with severe to profound hearing loss when a hearing aid is not a solution. Cochlear implants convert sound into electrical signals that are sent directly to the brain. A cochlear implant works in the following manner.

- An external processor is worn behind the ear or attached to the hair.
- The microphone in the external processor picks up the sound signal.
- The external processor digitizes the sound and transfers the electrical signal to the implant, which has been surgically placed in the cochlea.
- The implant acts like a miniature computer, deciphering the digitized sound and transferring it into electrical signals.
- The auditory nerve picks up the electrical signals and sends a message to the brain.
- The brain interprets the signals as sound.

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Animal horns were the first hearing aid, used in the 13th century. Technology has developed many improvements over the years. In 1878, Francis Blake and David Edward Hughes discovered that carbon transmitters could amplify sound, which was a big advance over the horn! In 1920, the vacuum tube was invented. The Radioear was the name of one of the hearing aids that used a vacuum tube. In 1950, Bell Laboratories invented the transistor battery, which was small and a big improvement over the vacuum tube. Since 1967 the digital hearing aid has been the main type of hearing device. It is small and convenient to wear. However, we know that, using technology, scientists will develop future improvements to help those with hearing loss.

The following might be an interesting experiment to try with a class of students. Can most people identify the smells correctly? Is there a significant difference in males and females of the same age?

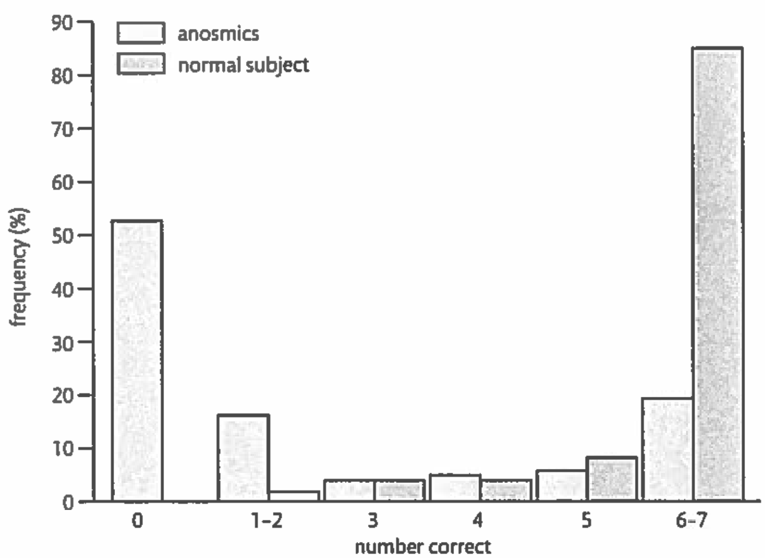

Figure 7.28 Anosmia.
Purves et al. 2001

Anosmia is the inability to identify common smells. When subjects are presented with seven common smells (a test frequently used by neurologists), the vast majority of 'normal' individuals can identify all seven smells correctly. The smells used for the graph shown were baby powder, chocolate, cinnamon, coffee, mothballs, peanut butter, and soap. Some people, however, have difficulty identifying even these common smells. When individuals already identified as anosmics were presented with these seven smells, only a few could identify all of them (less than 15%), and more than half could not identify any of them.

Section summary

- Our receptors, mechanoreceptors, chemoreceptors, thermoreceptors, and photoreceptors detect changes in our environment.
- Each part of the eye has an important function. The sense of vision is carried through the optic nerve to the brain.
- The retina contains two types of photoreceptor cells. They are the rods, which are more sensitive to light and function well in dim light, and the cones, which function in bright light.
- The three classes of cones are red, green, and blue. A red–green defect of the cone cells can be inherited as a genetic trait and is usually passed from mother to son.

To learn more about sensory organs and colour blindness, go to the hotlinks site, search for the title or ISBN, and click on Chapter 7: Section A.3.

CHALLENGE YOURSELF

Look at Figure 7.29 and answer the following questions.

13 What % of smells can people between the ages of 20 and 40 identify? Give a range.

14 What % of smells can people between the ages of 50 and 70 identify? Give a range.

15 What name do we give to data that fall far above or far below the line of best fit?

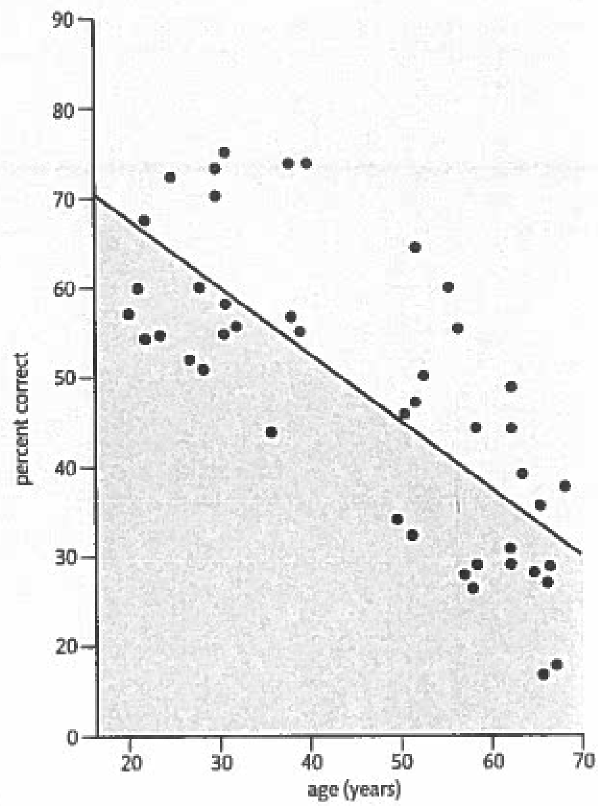

Figure 7.29 Normal decline in olfactory sensitivity with age. Purves et al. 2001

- Rods and cones synapse with bipolar neurones, which then synapse with ganglion cells. Ganglion cells send the impulses to the brain via the optic nerve.
- Information from the right field of vision from both eyes is sent to the left part of the visual cortex of the brain, and vice versa.
- The ear is used in both hearing and balance. Each part of the ear has an important function. Working together, the parts of the ear bring the sense of hearing via the auditory nerve to the brain.
- Medical technology can replace some parts of the human ear that are not functioning. For example, cochlear implants convert sound into electrical signals that travel to the brain.

To learn more about the evolutionary link between an animal's movement and its inner ear, go to the hotlinks site, search for the title or ISBN, and click on Chapter 7: Section A.3.