unit four

Brain, behaviour and experience

Area of study 1:
Learning

Area of study 2:
Mental health

chapter five

Learning

Key knowledge and skills

This knowledge includes:

- behaviours not dependent on learning including reflex action, fixed action patterns and behaviours due to physical growth and development (maturation)
- mechanisms of learning:
  - areas of the brain and neural pathways involved in learning, synapse formation, role of neurotransmitters
  - developmental plasticity and adaptive plasticity of the brain: changes to the brain in response to learning and experience; timing of experiences
  - use of imaging technologies in identification of localised changes in the brain due to learning specific tasks.

These skills include the ability to:

- formulate research questions and construct testable hypotheses
- use research literature to demonstrate how psychological concepts and theories have developed
- process and interpret information, and make connections between concepts and theories
- apply understanding to both familiar and new contexts
- evaluate the validity and reliability of psychology-related information and opinions presented in the public domain
- analyse issues and implications relating to scientific and technological developments.

LEARNING

Behaviours not dependent on learning

- Reflex action
- Fixed action pattern
- Maturation

Mechanisms of learning

- Areas of the brain involved in learning
  - Hippocampus
  - Amygdala
  - Frontal lobes
  - Cerebellum
- Synapse formation (synaptogenesis)
  - Neurotransmitters

Brain plasticity

- Adaptive
- Developmental
- Critical periods

Imaging techniques used to identify areas of learning in the brain

What is learning?

How do we learn? What happens in the brain during learning? How does learning affect behaviour? This chapter explores the characteristics of learning as a process that plays a part in determining behaviour. In doing so, we will explore the neural basis of learning.

Most human behaviour is learnt. Imagine if you suddenly lost all the information and skills you had ever learnt. What could you do? You would be unable to read or write. You couldn't feed yourself, find your way home, drive a car, play the guitar, or 'party'. Needless to say, you would be totally incapacitated.

Psychologists define learning as a relatively permanent change in behaviour (or behaviour potential) due to experience. When we say that what you learn – and the change in behaviour that results from the learning – is *relatively permanent*, we mean the change is stable and usually resistant to change. *Temporary* changes in behaviour caused by motivations, fatigue, disease, injury or drugs are not considered to be the result of learning.

Learning begins at birth and continues throughout our lifetime. It enables us to function on a daily basis and adapt to changes that are constantly occurring in the world around us.

BEHAVIOURS NOT DEPENDENT ON LEARNING

Although most human behaviours are acquired through learning and experience (after birth), some behaviours are innate (inborn) in many organisms. These inborn behaviours are programmed into our biology. Before we can explore learning in more detail, we must first understand the behaviours that do *not* depend on previous experience or learning.

Reflex actions

A reflex action is a simple, automatic, involuntary response to a specific stimulus that comes directly from the nervous system and is basically the same each time it occurs. For example, if a specific area of your knee is tapped with a mallet, your leg will automatically jerk; if air is blown in your eyes, you will automatically blink; and if lemon juice is squirted into your mouth, you will automatically salivate; if you are hungry, you will feel a sensation in your stomach. All of these reflex behaviours are innate (inborn), non-learnt behaviours that are 'hard-wired' into the nervous system. They do not require prior experience or conscious processing by the brain and they usually involve a single, simple, rapid response.

Reflexes are considered essential for survival because they allow us to react quickly to stimuli that may do us harm. For instance, if we didn't have the reflex whereby we retract our hands away from sharp things, we would probably often injure ourselves.

Fixed action patterns

A fixed action pattern (FAP), also known as a *species-specific behaviour*, is an innate or instinctive predisposition to respond in a particular way to specific environmental stimuli. These behaviours are essentially identical among most members of a species (though it may be limited to one gender or the other), and again appear to be 'hard-wired' to the nervous system.

Similar to reflex actions, FAPs are innate responses that are controlled by the nervous system; therefore, they cannot be changed by experience (learning). However, FAPs are typically more complex than a reflex because they usually involve a sequence of responses. For example, weaverbirds (a family of birds that includes the sparrow) are curious creatures that tie a special grass knot to hold their nests together. How do they learn to make the knot? They don't. Weaverbirds raised in total isolation for several generations still tie the knot the first time they build a nest (see Figure 5.1). Knot-tying in the weaverbird is a FAP – an instinctual, inherited (fixed) sequence of movements (pattern of actions) found in almost all members of the species that is performed

learning
A relatively permanent change in behaviour (or behaviour potential) due to experience

reflex action
A simple, automatic, involuntary response to a specific stimulus that comes directly from the nervous system and is basically the same each time it occurs

fixed action pattern (FAP)
The innate predisposition – essentially identical among most members of a species – to behave in a certain way in response to a specific environmental stimulus; also known as species-specific behaviour

Figure 5.1 Examples of fixed action patterns: Weaverbirds building their nests, salmon swimming upstream to spawn and spiders spinning webs

correctly the first time without previous experience. Other examples of fixed action patterns include spiders spinning their webs, and salmon swimming upstream to spawn in the same spot where they were once spawned (see Figure 5.1).

Like other innate behaviours, FAPs help animals meet major survival-related needs in their lives (consider a cat's washing routine, for example). More complicated behaviours, such as maternal instincts in lower animals, combine both fixed action patterns and various reflexes.

Human behaviours are not as instinctual as some non-human animal behaviours. Other than reflexes, no human behaviours are so rigidly programmed as to qualify as instinctive, but that doesn't mean that human learning is not affected by innate behaviour. Generally, humans adapt to their environment and respond accordingly so that they don't waste time and energy on unnecessary behaviours. They do not, however, have fixed action patterns.

Maturation behaviours

In humans, the emergence of many basic abilities, such as motor skills, crawling and walking, is closely tied to the developmental process of maturation. Maturation, which begins at conception, refers to the physical growth and development of the body, brain and nervous system that occurs at fairly predictable ages in the life cycle. Maturation behaviours are innate, genetically-programmed behaviours that *result* from the physical growth and development of the body, brain and nervous system at fairly predictable ages (see Figure 5.2).

Figure 5.2 Humans do not learn to walk – they do so due to maturation, when the body, brain and nervous system are prepared for the behaviour.

Although the rate of maturation varies from person to person, the *order* in which maturation behaviours occur is generally the same for all. The age at which the ability develops is also reasonably predictable. For example, the strength and coordination that a child will need to sit without support will appear before they have matured enough to crawl. A few children substitute rolling, creeping or shuffling for crawling. A very few move directly from sitting to standing and then to walking. Regardless of the rate of this maturation, an orderly sequence of motor development remains evident.

Table 5.1 summarises the three types of behavioural changes that are not dependent on learning.

Table 5.1 Behaviours not dependent on learning

BEHAVIOURS NOT DEPENDENT ON LEARNING		EXAMPLE
Reflex action	• Simple (usually a single response) • Involuntary response to a specific stimulus • Not species-specific • Basically the same each time it occurs	Blinking when air is blown at the eye
Fixed action pattern	• Complex • A sequence of responses/ behaviours • Species specific • Linked to environmental stimuli	A spider spinning a web
Maturation	• Physical growth of the body (brain, nervous system, muscular system) due to changes occurring in the nervous system at predictable ages in the life cycle	Crawling, walking

'Try it yourself 5.1' highlights the fact that there are limits or constraints among different species when it comes to learning. Complete 'Try it yourself 5.2' to further examine behaviours not dependent on learning.

TRY IT YOURSELF 5.1
Is it easy to learn new things?

For humans, some associations between stimuli and responses, or between responses and consequences, are easily learnt. Others can only be acquired with great difficulty.

For example, try the following: draw a clockwise circle on the floor with the big toe of your right foot; at the same time, hold your right hand at waist level and move it in a counter-clockwise circle, parallel to the floor.

Even if you were offered a substantial reward, you might find it difficult to learn these biologically atypical movements!

TRY IT YOURSELF 5.2
Finding out about behaviours not dependent on learning

In small groups, research examples of reflex actions, fixed action patterns and maturation behaviours in different species. Choose two good examples of each type of behaviour not dependent on learning and prepare a presentation to give to the class, outlining the behaviours you examined. Your presentation can be accompanied by visuals.

CHECK YOUR UNDERSTANDING 5.1

1 Identify the survival purpose each of the following reflex actions.
   a Sweating
   b Sneezing
   c Salivation
   d Blinking

2 Match each term with its correct definition.

a Learning	i The physical growth and development of the body, brain and nervous system at fairly predictable ages
b Reflex action	ii Innate, age-related behaviours that result from the physical growth and development of the body, brain and nervous system at fairly predictable ages
c Maturation	iii An involuntary response to a specific stimulus that is controlled by the nervous system
d Maturation behaviour	iv The innate predisposition to behave in a certain way, in response to a specific environmental stimulus, that is essentially identical among most members of a species
e Innate behaviour	v A relatively permanent change in behaviour (or behaviour potential) due to experience
f Fixed action pattern	vi A simple, automatic, involuntary response to a specific stimulus that comes directly from the nervous system and is basically the same each time it occurs

3 Fill in the gaps with the correct word(s).
   a An instinctual chain of responses found in nearly all members of a species is called a ______________ ____________________________.
   b A reflex occurs ______________, without conscious thought or prior knowledge.
   c The biological emergence of innate tendencies as a result of ageing is known as ______________.

4 When sparrows engage in the same sequence of behaviours when building a nest this is an example of:
   A a reflex action.
   B a fixed action pattern.
   C a maturation behaviour.
   D learning.

5 Indicate whether the following statements are true (T) or false (F).
   a Fixed action patterns are simple, single, innate responses to specific environmental stimuli.
   b Blinking in response to a puff of air being blown at your eyeball is a reflex action.
   c Learnt responses are inbuilt into the nervous system at birth.
   d A four-month-old baby can learn to walk.

The physiology of learning

One of the greatest challenges of science today is to understand how the brain functions. In order to understand this, neuroscientists study the structure and function of the nervous system, particularly the central nervous system (CNS), which consists of the brain and spinal cord. As we learned in chapter 2, the brain receives and processes stimuli – and it also decides how we will respond to stimuli. These decisions are relayed to the body via the spinal cord, which links to the peripheral nervous system (PNS). The PNS then carries the instructions for actions to the muscles, organs and glands involved in performing the behaviour. The multitude of brain and nervous system functions determine who we are and how we will respond to stimuli.

The nervous system, and therefore the brain, is a living organ that grows and changes continuously in response to in-built genetic programs and to its interactions with the environment. The brain is about the size of a large grapefruit and consists of approximately 100 billion neurons that receive messages from other neurons, process them, and transmit them to other neurons. Each neuron in the brain is linked to as many as 15 000 others, and millions of neurons must send messages at the same time to produce even the most fleeting thought (Carter, 1998). Neurons link to one another in tight clusters and long 'chains'. This network makes it possible to combine, transmit and store immense amounts of information.

The mass of neurons we call the human brain enables us to make decisions, solve problems, fall in love or read a book – it also enables us to learn.

maturation
The physical growth and development of the body, brain and nervous system at fairly predictable ages in the life cycle

maturation behaviours
Innate, age-related behaviours that result from the physical growth and development (maturation) of the body, brain and nervous system at fairly predictable ages in the life cycle

Thus, everything you do, think, or feel can be traced back to these tiny cells.

To understand the physiological mechanisms involved in learning, scientists have studied the physical changes that occur in the brains of animals such as rats, cats, frogs, chimpanzees and snails (as well as human subjects) during learning, as well as the changes in behaviour produced by these brain changes.

However, the study of the human brain (both intact and damaged) can be problematic due to the brain's structural and functional complexity, and the vast number of neurons that make up its neural networks. As mentioned in chapter 3, neuroscientists interested in the physical mechanisms of learning have found that species such as the aplysia (sea snail) are easier to study than more complex animals. Because the neural circuits of the aplysia are simplistic, any behavioural changes they experience as a result of learning can be analysed neuron by neuron. This approach to the study of the brain is called the simple-systems approach.

BRAIN AREAS INVOLVED IN LEARNING

Over our lifetime we will learn a countless number of behaviours, many of which will involve different areas of the brain. Studies have shown that the nature of the behaviour being learnt affects which brain areas are activated. For example, learning certain types of motor skills – especially those requiring balance and coordination, such as riding a bicycle – activates structures in the hindbrain; learning to navigate in space activates midbrain structures; and cognitive learning activates forebrain structures such as the frontal lobe.

Studies of individuals who have experienced damage to specific brain structures support the theory that these structures and areas have some involvement in most types of learning. Figure 5.3 shows the specific brain structures involved in learning, which we will now explore.

The cerebellum: 'Little brain'

The cerebellum (sometimes called the 'little brain') is a structure attached to the rear of the brainstem that helps coordinate voluntary movement and balance. The cerebellum primarily regulates posture, muscle tone and muscular coordination. The cerebellum also stores memories related to skills and habits (Thompson, 1991).

In one study of the cerebellum's involvement in learning, the cerebellums of rats raised in an enriched environment (where they could exercise and be active) were compared to cerebellums of rats raised in small cages (with no space to exercise). Results showed that the cerebellums of the exercised/enriched rats were more highly developed (Volkmar & Greenough, 1972). (This study will be investigated further later in this chapter; page 163.)

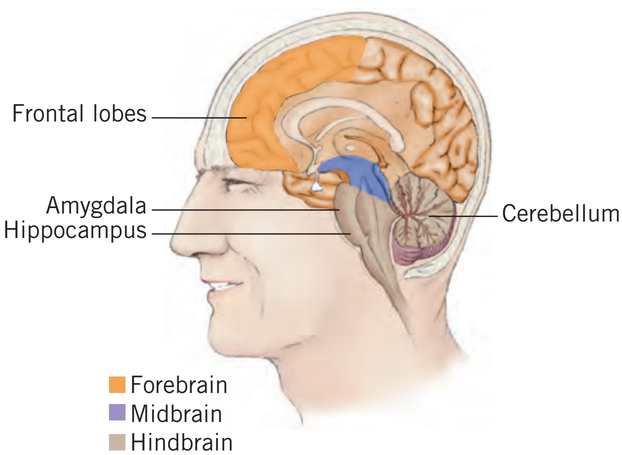


Figure 5.3 Learning is not confined to a single brain area. Some of the brain areas thought to be involved in most types of learning are the cerebellum, frontal lobes and the hippocampus and amygdala.

The cerebellum is also implicated in neural circuits involved in simple stimulus–response learning (classical conditioning – see chapter 6) (Donegan, Gluck & Thompson, 1989).

The limbic system's hippocampus and amygdala

The limbic system is composed of a number of structures that form a doughnut-shaped neural system between the hindbrain and the cerebral hemispheres.

The first of the limbic system's key structures is the *hippocampus*. In chapter 3 we examined the role of the hippocampus and the temporal lobe in memory (see pages 105–6). We discovered that if these areas are damaged, an organism may be unable to formulate or store new memories of facts or episodes. Among other things, we learnt that the hippocampus is considered critical to spatial learning and awareness because it plays a role in monitoring locations in space and the relationship between them, so it acts as the brain's geographer (McClelland, McNaughton & O'Reilly, 1995; Tulving & Schacter, 1994). The hippocampus is involved in learning how to navigate through space. It is crucial to the formation and storage of episodic memories and it has also been identified as a site for a variety of declarative learning and memory functions.

Studies into the role the hippocampus plays in spatial learning have involved rats and monkeys. When researchers put lesions in the hippocampus of rats, the rats could not learn to navigate a maze (Olton, Collison & Werz, 1977). Similarly, monkeys with lesions to their hippocampus could not learn the location of hidden food (Mishkin & Appenzellar, 1987).

Although the hippocampus is heavily involved in many forms of learning, it is not involved in the learning of everything. For example, you can learn certain skills without the hippocampus. These skills are known as non-declarative skills, which are usually procedural tasks, such as learning to ride a bike.

The amygdala is the second key structure in the limbic system, a cluster of neurons in the limbic system that is involved in a number of functions – there are nerves connecting it to several important brain centres such as the brainstem and the cortex.

In humans and other animals, the amygdala's main function is to aid survival behaviour, and it is involved in the memory and learning of emotional responses, particularly related to aggression and fear (fight–flight). The amygdala provides a primitive 'quick pathway' to the cortex, which enables us to react to dangerous stimuli before we have fully comprehended the situation. When the amygdala is stimulated, animals will respond with aggression or rage.

The frontal lobes

The frontal lobes are the cortical lobes that perhaps still remain the biggest mystery to researchers. Research findings show that damage to the frontal lobes causes disruption to a greater variety of skills than damage to any other lobe. These findings indicate that frontal lobe functioning is crucial to cognitive behaviours such as learning, memory, planning, problem-solving, speech production and the execution of daily activities. The most well-documented function of the frontal lobes is their involvement in motor functions.

Some patients with damage to their frontal lobes have had no impairment to their intelligence; however, their ability to plan and their motivation are seriously impaired. Kolb and Whishaw (1990) described a man who was a successful lawyer before damaging his frontal lobes. When given an intelligence test after the damage, his IQ was the same as before the damage, as was his professional talent. However, he could not get up in the morning and was unable to get himself to work. He found it difficult to learn new tasks, perhaps due to the lack of motivation and the inability to plan.

CHECK YOUR UNDERSTANDING 5.2

1 Fill in the gaps with the correct word.

a The two key components of the ________ system are the _________ and the amygdala.

b Sometimes called 'little brain', the _______ is a structure attached to the rear of the brainstem that helps coordinate voluntary movement and balance.

c The hippocampus does not appear to play a role in the learning of __________ skills.

d The _______ is a cluster of neurons in the limbic system that influence learning and behaviour, particularly related to the emotions of aggression and fear.

2 Match each term with its correct definition.

a Amygdala	**i** A cluster of neurons in the limbic system that is associated with learning and initiating fear responses
b Cerebellum	**ii** A number of structures that form a doughnut-shaped neural system between the hindbrain and the cerebral hemispheres
c Frontal lobes	**iii** A structure attached to the rear of the brainstem that helps coordinate voluntary movement and balance
d Limbic system	**iv** Structures crucial to cognitive behaviours such as learning, memory, planning, problem-solving, speech production, and the execution of daily activities

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

a The cerebellum is a structure attached to the rear of the frontal lobe that helps coordinate voluntary movement and balance.

b Different types of learning involve different parts of the brain.

c The hippocampus is located in the frontal lobes of the brain.

d The hippocampus is involved in spatial learning and awareness.

Continued

cerebellum
A structure attached to the rear of the brainstem that helps coordinate voluntary movement and balance

limbic system
A number of structures that form a doughnut-shaped neural system between the hindbrain and the cerebral hemispheres

amygdala
A cluster of neurons in the limbic system that is associated with learning and initiating fear responses

4 The amygdala is a part of the:

- A digestive system.
- B respiratory system.
- C limbic system.
- D sympathetic nervous system.

5 The frontal lobes are thought to be involved in which of the following functions?

- A Planning
- B Problem-solving
- C Learning
- D All of the above

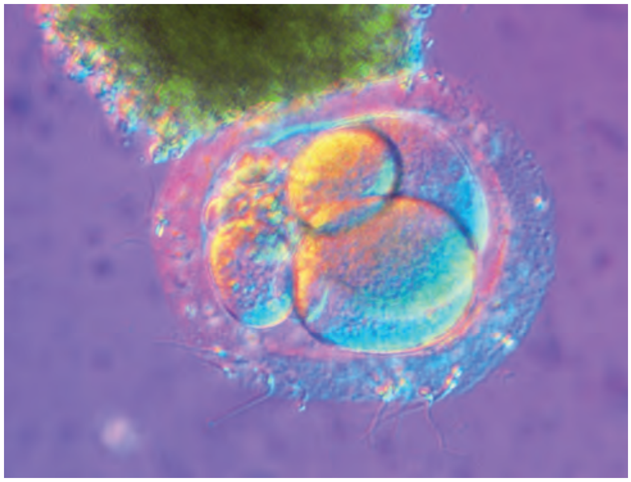


Figure 5.4 As the zygote (basic cell) divides and multiplies, new cells are formed.

PHASES OF NEURAL DEVELOPMENT IN LEARNING

Donald Hebb, a Canadian psychologist (1946), hypothesised that the way cells assemble is the critical building block for learning. He theorised that when two neurons are jointly activated, they become more closely linked. Hebb's theory was debated for many years, and although not all details are supported, most researchers now agree that when learning takes place a physical change occurs in the synapse between neurons (Hawkins & Bower, 1989). These changes result in the laying down of new neural circuits, or neural pathways, through which information can travel around the brain.

One of the most important properties of neural circuits is that they can change; that is, they can learn. We know that the capacity to learn is crucial to survival, as it supports an organism's adaptability to their ever-changing environment. But how does learning actually occur in the brain? The answer to this is complex, but if we are to process information and learn from it, the first thing that must happen in our brain is that the neurons must be able to communicate.

Neuron formation: Laying the groundwork

A basic cell begins with a zygote (a single cell formed when sperm comes in contact with an ovum). The zygote divides to form two daughter cells, which divide and start to multiply (see Figure 5.4). Each cell will divide to form two cells; those two cells will divide to form four; and so on until a single, large organism is produced. This process, known as *multiplication*, may sound simple, but it is in fact very complex.

Besides multiplying, the cells must *differentiate*. This means that some will become muscle cells, some will become glial cells (cells that are not neurons but that support, nourish and protect neurons) and others will become multipolar cells (neurons with one axon and three or more dendrites). These different types of cells must then make their way to the appropriate sites in the organism and line up with other cells to form particular structures. Finally, the cells must begin to create a relationship with cells around them. In other words, they must form *synapses*, in a process called *synaptogenesis* (Pinel, 1997) – we will investigate this process next.

As you can see, this process results in a variety of cells that differ in structure as well as function, and this variety ensures that the organism is capable of the multitude of behaviours it needs to produce in order to survive.

SYNAPSE FORMATION: SYNAPTOGENESIS AND ITS LINK TO LEARNING

As we know, different parts of the brain have different functions and the links (neural pathways) between them need to be built and maintained. During learning, nerve cells grow new connections and form new synapses, or existing synapses are strengthened. Information is then able to pass from one neuron to the next. Once this information transfer happens, the information is learnt.

Not all brain neurons have synaptic connections with other neurons when we are born – the synapses (connections) must form as our brain continues to develop. Synaptogenesis is the term used to describe this formation of synapses (connections) between neurons. Once neurons have migrated to their appropriate positions within the body, axons (thin fibres that carry information away from the neuron's cell body) and dendrites (neuron fibres that receive incoming messages) begin to grow from them. At the tips of the axons and dendrites, structures called growth cones are found, which extend out finger-like extensions called filopodia (see Figure 5.5). These filopodia appear to search for the correct route to the target cell (Stirling & Dunlop, 1995). Synaptogenesis then occurs: the axons and dendrites project out and link with a target cell, or form a synapse (see Figure 5.6).

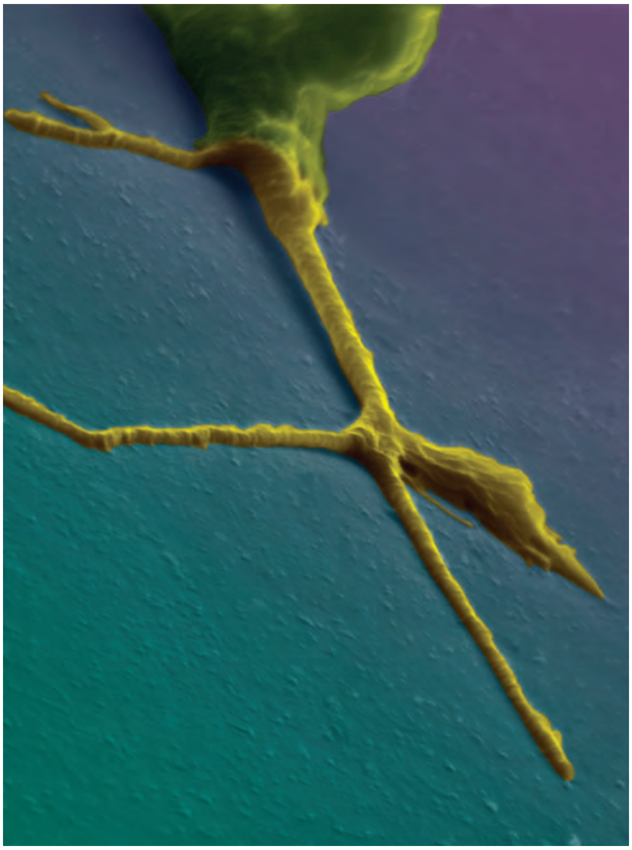


Figure 5.5 A cultured sensory neuron extending a growth cone with long thin filopodia

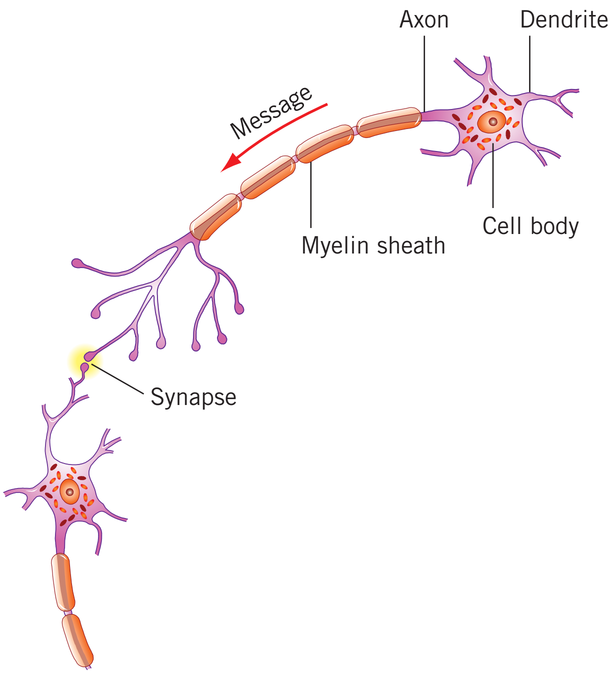


Figure 5.6 Synaptogenesis has occurred to produce the synapse between these two cells, to enable them to communicate.

Synaptogenesis occurs throughout a healthy person's lifespan, but it occurs most rapidly during early brain development, beginning at about two months before birth until approximately two years after birth. Synaptogenesis allows us to form many new synaptic connections between neurons to establish the neural pathways that allow different brain areas and structures to communicate. Those pathways that are most often stimulated and strengthened (due to being used most often) become a permanent part of the brain.

There are a number of hypotheses proposed to explain how the filopodia on the tips of the axons and dendrites find the appropriate target cell. 'A closer look: Growth cones and target cells' examines these hypotheses.

A CLOSER LOOK

Growth cones and target cells

Three hypotheses have been proposed to explain how growth cones find the correct target cells.

Chemoaffinity hypothesis:

In 1943, Roger Sperry conducted a series of experiments on the growth of axons in the visual systems of frogs. In one experiment, he cut the optic nerve of the frogs, and rotated their eyeballs 180 degrees on a horizontal axis (so that what used to be the top of the eyeball was now the bottom). The frog is an unusual species as, unlike mammals, they have retinal ganglion cells that regenerate. So, after he cut the optic nerves, Sperry waited until the cells grew again and then tested the visual capacities of the frogs.

When Sperry dangled a lure *behind* these frogs but still within their sight, they stuck their tongues out in a *forward* motion to catch it, instead of correctly sticking their tongues out behind them. This indicated that their visual world had been rotated 180 degrees (essentially upside down), like their eyes.

In another experiment, Sperry rotated the frogs' eyeballs 180 degrees but did not cut their optic nerves. These frogs responded in exactly the same way as those that had their optic nerves cut.

This led Sperry to conclude that each retinal ganglion cell in the cut optic nerve had grown back to the same part of the optic tectum (the main destination of visual neurons in lower vertebrates) to which it had originally been connected (see Figure 5.7) (Sperry, 1943a, 1943b).

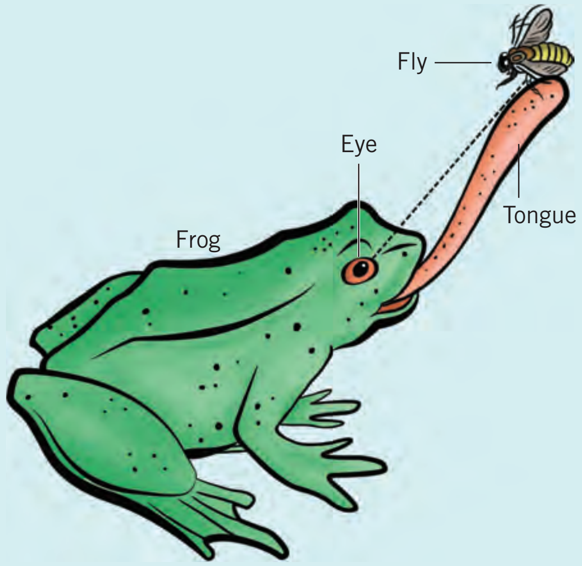
Sperry then proposed the chemoaffinity hypothesis of axonal development. He hypothesised that post-synaptic (receiving) neurons release a chemical that attracts the growing axons of pre-synaptic neurons so that they find their target cells during both development of connections and the regeneration of connections.

Continued

synaptogenesis
The process by which synapses are formed between neurons

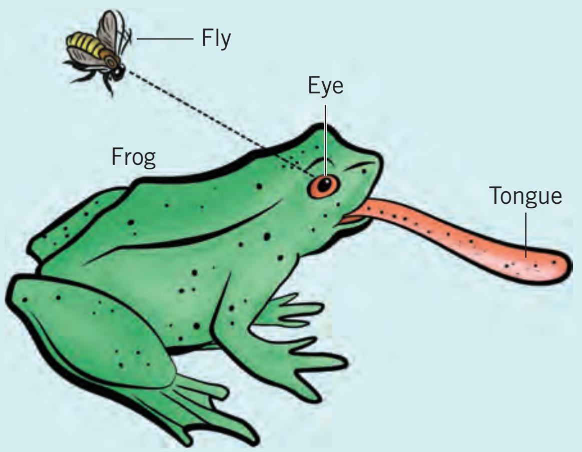
filopodia
Finger-like extensions of growth cones (structures at the tips of axons and dendrites) that search for target cells during the process of synaptogenesis

a Frog with intact optic nerve



When a fly is dangled in front of a normal frog, the frog will stick its tongue out accurately in a forward motion to catch it.

b Frog with cut optic nerve/regenerated optic nerve



When the eye is rotated 180 degrees without cutting the optic nerve, the frog will misdirect its tongue by 180 degrees. To catch a fly located behind it, the frog sticks its tongue out in front. When the optic nerve is cut and the eye is rotated 180 degrees, the optic nerve regenerates. The frog will stick its tongue out but it will still misdirect by 180 degrees. This is because the axons in the optic nerve, although rotated, will grow back to the original synaptic sites.

Figure 5.7 Sperry's study on the growth of axons in the visual systems of frogs

There is evidence to support this theory, some from cases where developing neurons have been shown to grow to their normal targets in cells in tissue culture (in vitro). However, this theory cannot explain why targets transplanted to new positions will sometimes create synapses with incorrect target cells. For example, when a chick embryo was implanted with an extra thigh segment in the leg, this extra bit became innervated by the axons that normally innervate the calf (Whitelaw & Hollyday, 1983).

Blueprint hypothesis:

This hypothesis purports the existence of 'Pioneer' growth cones, which are the first growth cones to travel along a particular route in the developing nervous system. These Pioneer growth cones are the 'trailblazers', so to speak. All subsequent growth cones are thought to follow the routes taken by the Pioneer growth cones; this is called fasciculation. In an experiment where Pioneer axons in a fish spinal cord were destroyed with a laser, the subsequent axons of the same nerves did not reach their usual destination (Klose & Bentley, 1989; Kuwada, 1986).

This hypothesis can account for some aspects of cell growth; however, it cannot explain the ability of some developing axons to reach their target cells or correct destination.

Topographic gradient hypothesis:

According to this hypothesis, the axons from one sheet of cell bodies grow out to another, and arrange their synapses according to the relative position.

Complete 'Try it yourself 5.3' to consolidate your learning about the neural processes involved in learning.

TRY IT YOURSELF 5.3

Neural processes and learning

Create a PowerPoint presentation that shows the neural processes involved in learning. Your presentation should include terms and processes such as:

- Synapse formation (synaptogenesis)
- Axon, dendrite, synapse
- Neurotransmitters
- Brain

EFFECTS OF EXPERIENCE ON NEURAL DEVELOPMENT

Genetically, a cell may be programmed to find its target cell and establish a synapse. Even so, many potential synaptic connections are lost, and up to 50 per cent of neurons die during the time of synaptogenesis in most regions of the developing nervous system (Oppenheim, 1991).

It is clear, then, that genetics alone do not determine neural development – the external environment also plays a part. The main principle that governs the effects of experience on neural development is 'use it or lose it'. Donald Hebb was one of the first to propose that use of a function increases neural structure, whereas disuse decreases it. This principle suggests that neurons that are not activated by experience do not survive (Hockfield & Kalb, 1993; Kalil, 1989).

Some of the earlier studies that have demonstrated the influence of experience on neural development include those on visual deprivation. For example, animals reared in the dark were found to have fewer synapses (Cragg, 1975) and fewer dendrites (Valverde, 1971) in their primary visual cortices than animals reared in their natural environment. They were also unable to judge depth correctly (Walk & Walters, 1973) and they had deficits in their pattern vision as adults (Tees, 1968).

Other studies into the influence of early exposure to enriched environments on animal neural development support this. They suggest that enriched experience results in greater synapse formation. In one study, rats that were raised with other rats in enriched environments (complex cages) were found to have thicker cortices with more dendritic development (Greenough & Volkmar, 1973) and more synapses per neuron (Turner & Greenough, 1983) than rats raised by themselves in simple cages (see Figure 5.8). In fact, there was 23 per cent more branching of the dendrites in the cells of the cerebellum of the enriched rats when compared to the rats in simple cages. Similarly, rats raised in an enriched environment showed increased branching of dendrites in the primary visual area of the cerebral cortex (Greenough & Juraska, 1979; Volkmar & Greenough, 1972).

These studies suggest that learning through experience can play a big part in how our synapses form.

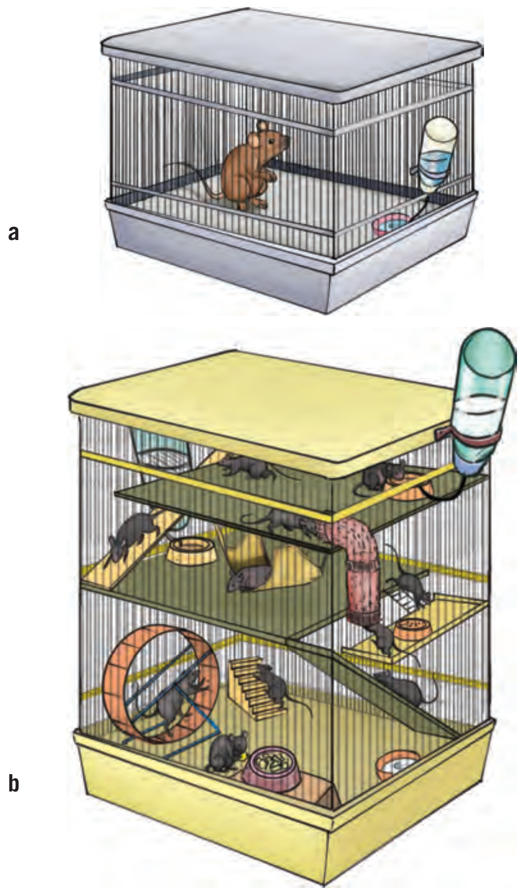


Figure 5.8 Rats raised in an enriched environment (b) show greater synapse formation and thicker cortices (with more dendrite development) than rats raised in simple cages (a).

'A closer look: Changes in the fledgling's brain' examines new findings that show changes in the brain of a juvenile bird when it hears the song of an adult bird.

A CLOSER LOOK

Changes in the fledgling's brain

Scientists have seen brain cells in an adolescent finch change as it listened for the first time to the warble of an adult bird.

The experiment has won praise for unlocking insights into the learning process, and proving that just a single experience can rapidly shape a juvenile brain and alter the way it functions.

Whether in birds or humans, acquiring the ability to perform certain acts is critically important for survival, said Richard Mooney, a professor at Duke University in Durham, North Carolina. 'A male songbird has to learn to sing precisely or he won't attract a mate.'

Previous studies have pointed to a link between structural changes in the brain and sensory input. But whether these changes lead to learning remained uncertain.

To find out, Professor Mooney and other researchers peered directly into the brain of an anaesthetised immature bird with a laser-powered microscope. As it heard the song of a mature male from the same species, they witnessed a dramatic transformation in connective tissue – called dendritic spines – that links nerve cells in the brain.

Yet the change was not the one they had anticipated.

'We expected to see the building of new spines and the loss of old spines accelerate,' Professor Mooney said.

This is because it can take weeks or months for a juvenile to master the adult song. As a result, the scientists assumed that the brain would remain highly malleable, or 'plastic', during that period.

Instead they saw exactly the opposite: hearing a tutor song rapidly stabilised previously dynamic synapses, according to the study, published in the journal *Nature* on Wednesday.

The findings also suggest that the opportunity for picking up the all-important mating song ended abruptly after a certain age.

The work could help efforts to restore plasticity to cerebral nerves, called synapses, after a stroke or other brain damage, said lead author Todd Roberts.

Source: *The Age* (2010) 'Boffins watch love song alter fledgling's brain.' February 19.

CHECK YOUR UNDERSTANDING 5.3

1 The contacts between neurons can be lost during development, and up to ____ of neurons die during synaptogenesis.

A 20%

B 30%

C 40%

D 50%

Continued

163

2 The role of the filopodia is to:
 A deter potential synapses from forming.
 B attract the positive ions in the cells and destroy them.
 C search for the correct route to the target cell.
 D teach the cell to move.

3 Match each term with its definition.

a Donald Hebb	i The finger-like extensions of the axon and dendrites that search for the target cells
b Synaptogenesis	ii A Canadian psychologist who theorised about neural development in cells
c Multiplication	iii A single cell formed when the sperm comes in contact with an ovum
d Filopodia	iv When cells divide and reproduce
e Zygote	v When different cells are formed
f Differentiation	vi When a synapse is established

4 Place the following terms relating to neuron formation in the correct order in the sentence.
- multiplication
- synaptogenesis
- differentiation

A basic cell begins with a zygote, then ________ and _________ occur before the final process of _____________ takes place, which enables the cells to communicate.

5 Indicate whether the following statements are true (T) or false (F).
 a A single cell formed when the sperm comes in contact with an ovum is called a filopodia.
 b Glial cells support, nourish, and protect neurons.
 c Synaptogenesis refers to synapse formation between neurons.
 d Synaptogenisis occurs most rapidly during early brain development, beginning at about two months before birth until approximately two years after birth.
 e Most researchers agree that when learning takes place a physical change occurs in the synapse between neurons.

The role of neurotransmitters in learning

Learning involves the introduction of experience or new information, which produces changes in neurons and neural networks. Through learning, new synapses grow and existing synapses form closer links.

As we know, neurons must communicate over the synapse (synaptic gap) because neurons are not joined to one another. So how does a message travel across the synapse from one neuron to another?

The nerve impulse *within* a neuron is primarily electrical. That's why behaviour is affected when the brain is electrically stimulated. In contrast, communication *between* neurons is chemical, so messages are sent between neurons chemically. The sending neuron is known as the pre-synaptic neuron (i.e. before the synapse) and the receiving neuron is known as the post-synaptic neuron (i.e. after the synapse). When an electrical charge in the form of a nerve impulse, or action potential, sweeps down the axon, neurotransmitters are released into the synapse. As we learnt in chapter 3, neurotransmitters are chemicals released at the axon terminal of the pre-synaptic neuron. They carry the chemical messages across the synapse to the dendrite (receptor site) on the post-synaptic neuron (see Figure 5.9). Neurotransmitters therefore enable communication between neurons and enable messages to travel from sensory receptor sites to the brain.

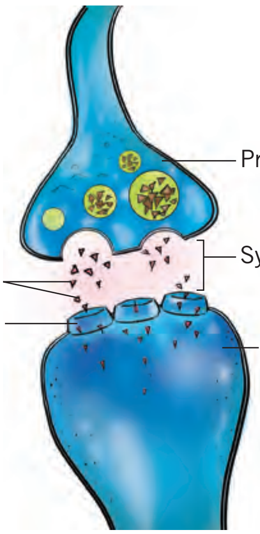


Figure 5.9 Neurotransmitters are chemicals that cross the synaptic gap from the pre-synaptic neuron and attach to receptor sites on the post-synaptic neuron.

Neurotransmitters may act in one of two ways when they arrive at the post-synaptic neuron. Transmitters may *excite* the post-synaptic neuron (that is, make it more likely to fire an action potential) or *inhibit* it (that is, make it less likely to fire an action potential). At any instant, a single neuron may receive hundreds or thousands of messages from adjacent neurons. However, whether the result of synaptic transmission will be excitatory or inhibitory depends on the type of neurotransmitter used and the electrically-charged receptors (ion channel receptors) they interact with.

See 'A closer look: Types of neurotransmitters' for more details on specific types of neurotransmitters

VIDEO

Neural synapse

and how they are used. View 'Videolink: Neural synapse' to see a visual representation of how neurotransmitters travel across the synapse.

A CLOSER LOOK

Types of neurotransmitters

Excitatory synaptic transmission uses a neurotransmitter called L-glutamate, which is the major excitatory neurotransmitter in the CNS. It interacts with glutamate receptors in the post-synaptic neuron. Inhibitory synaptic transmission uses a neurotransmitter called GABA. This interacts with GABA receptors – ion channels that are permeable to negatively-charged chloride ions. Thus, opening of these channels makes it harder for a neuron to generate an action potential.

In addition to L-glutamate and GABA, there are more than 100 other neurotransmitters and their receptors that also perform vital functions in the brain, some of which are excitatory and some of which are inhibitory.

Dopamine

The neurotransmitter dopamine is thought to contribute to attention, learning and motor movement. It is dispersed from specific neurons in the brain and influences the activity of a large number of other neurons.

Reduced dopamine concentrations in the frontal lobes are thought to contribute to attention deficit disorder and Parkinson's disease. Excesses of dopamine have been linked to schizophrenia (see chapter 8).

Norepinephrine

The neurotransmitter norepinephrine is secreted by the medulla and the neurons of the sympathetic nervous system. Norepinephrine influences the degree of alertness in the brain, controls hunger, and is involved in learning and memory. It is involved in a range of emotional experiences and lower levels of norepinephrine are associated with depression.

Seratonin

The neurotransmitter serotonin is produced in the CNS as well as the intestines. It is involved in many processes including pain, sleep and mood regulation. It is mainly an inhibitory neurotransmitter, lower levels of which have been associated with mood disorders, anxiety and sleep disorders.

CHECK YOUR UNDERSTANDING 5.4

1 Fill in the gaps with the correct terms.

a The sending neuron is known as the ________ neuron. The receiving neuron is known as the ________ neuron. When an electrical charge in the form of a nerve impulse, or ____________, is sent down the axon, the axon terminals release ____________.

b The transmission of an impulse within neurons is ____________, but transmission between neurons is ____________.

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

a Transmitters may excite the next neuron or inhibit the next neuron.

b At any instant, a single neuron may receive hundreds or thousands of messages.

c The release of a neurotransmitter will immediately trigger an action potential in the next neuron.

d The axon terminals of one neuron actually connect with the dendrite of another neuron.

e Learning involves the introduction of experience or new information, which does not produce any change to neurons.

f A chemical charge in the form of a nerve impulse is called an action potential.

3 Which one of the following statements is true about neural transmission?

A The transmission of an impulse occurs only within the central nervous system.

B The transmission of an impulse within neurons is chemical.

C The transmission of an impulse between neurons is chemical.

D The transmission between one neuron and another relies on the electrical conductivity of the neuron.

4 Neurotransmitters:

A are chemicals released at the synapse of a nerve cell.

B can stimulate activity in an adjacent neuron.

C can inhibit activity in an adjacent neuron.

D All of the above

5 Match each term with its correct definition.

a Synapse	i The neuron that receives information from another neuron
b Action potential	ii The neuron that sends information to another neuron
c Neurotransmitter	iii The small gap between two neurons
d Post-synaptic neuron	iv The chemical message sent from one neuron to another
e Pre-synaptic neuron	v The electrical nerve impulse that flows within a neuron

pre-synaptic neuron
A neuron that sends a nerve impulse across the synapse to another neuron (post-synaptic neuron)

post-synaptic neuron
A neuron that receives a nerve impulse sent across the synapse from another neuron (pre-synaptic neuron)

action potential
An electrical charge (nerve impulse) that sweeps down the axon of a neuron, prompting the release of neurotransmitters

Plasticity: Rewiring the brain

If something is plastic, it means that it can be moulded and changed. For example, a lump of plasticine can be transformed into whatever shape we want; it does not have a fixed shape. In terms of the human brain's capacity to learn, research studies indicate that the human brain can also be moulded and changed throughout the lifespan. In other words, the brain has the ability to change its structure and relocate functions to different areas and/or neuronal networks. This is known as plasticity. These studies also indicate that the environment in which a person lives, as well as the actions of that person, play a role in plasticity.

There are three circumstances under which brain plasticity can occur:

1 at the beginning of life, when the immature brain organises itself
2 in case of brain injury, to compensate for lost functions or maximise remaining functions
3 throughout life, whenever something new is learnt and memorised.

DEVELOPMENTAL AND ADAPTIVE PLASTICITY

Developmental plasticity is a term referring to changes in neural connections during development, which result from environmental interactions and learning experiences. Developmental plasticity is specific to changes in neurons and synaptic connections as a consequence of *developmental processes*.

When the brain is in its developmental stages, dramatic changes occur in neuron numbers. During development of the nervous system, cells divide, differentiate, extend axons and dendrites, and form synapses. During brain development and also during other periods of change (such as maturation), synaptic connectivity can also change, and the post-synaptic response to the release of neurotransmitters is not necessarily always the same (it can be made stronger or weaker).

We might think that the brain is only plastic during developmental periods; however, the brain is still capable of plasticity throughout adult life. The major structures in the human brain are basically the same for everyone, but subtle differences between the brains of different individuals result from the fact that it is adaptable and able to modify its circuits in various ways throughout life. This is what makes our behaviour flexible and efficient (Conlan, 1999; Posner & Levitin, 1999).

Remarkably, the brain can 'rewire' itself after some types of damage. It also forms new connections in response to changing environmental conditions (Hyman, 1999; Kolb & Whishaw, 1998) as well as neural changes induced by learning. We call this adaptive plasticity, and it occurs when the connections between the synapses are altered to best suit the environmental conditions, when learning something new or when re-learning something after brain injury or surgery.

The surprising discovery that the brain can actually change its shape within weeks in response to certain mental and physical stimuli differs from the traditional concept that brain shape must remain unchanged except as a result of neurologic disorders. Investigations into the brain's adaptive plasticity have been undertaken in the past, but it was not until recently that the effect of learning on larger structural changes in the brain was observed. In the 19th century, the practice of *phrenology* attempted to map personality attributes by observing bumps on the head, and was eventually discredited. It is only now that researchers have finally demonstrated that certain parts of the brain are function-specific and may actually *grow* with learning, and therefore alter in shape.

So how does this adaptive 'rewiring' occur? Learning a new skill, such as playing the piano, requires many changes in the brain. Some dendrites grow longer and sprout new branches; others are 'pruned' away. New synapses form, while others disappear. Activity levels change in groups of neurons. Through such processes, parts of the cortex are 'rewired' and 'tuned' to carry out tasks more efficiently (Johnson, 1999). For example, as a result of cortical tuning, distinct areas of your brain are especially good at recognising faces, animals, furniture and other specific types of objects. Likewise, the brain of an adult violinist will be different if she began practising as a child, rather than later in life (Posner & Levitin, 1999). Over the course of a lifetime, our experiences literally shape, mould and remodel details of the brain.

In his 2007 book, *The Brain That Changes Itself: Stories of Personal Triumph from the Frontiers of Brain Science*, Norman Doidge describes numerous examples of functional shifts. One of the stories is about a surgeon who suffered a stroke that left him with paralysis in his left arm. Part of his rehabilitation was not to use his good arm; to instead make himself use his left arm. When the patient was asked to clean tables, at first the task was not possible because he could not use his right arm and his left arm was paralysed. Then, bit by bit, he began to remember how to move his left arm. Eventually, he learnt to write and play tennis again (Doidge, 2007). In this case it would appear that the functions damaged by the stroke transferred themselves to regions of the brain that were unaffected by the stroke. The brain compensated for damage by reorganising and forming new connections between intact neurons and, in order to reconnect, the neurons had to be stimulated through activity.

VIDEO
Brain plasticity

'Videolink: Brain plasticity' examines an extraordinary case of brain plasticity demonstrated after radical brain surgery.

IMPLICATIONS OF BRAIN PLASTICITY

Psychologists used to think that we cannot 'exercise' our brain in any general sense. However, studies of neural plasticity do suggest the concept of 'use it or lose it'. Using your brain in novel or stimulating ways actually increases its size and the number of dendritic branches it contains (Kempermann & Gage, 1999). The more you challenge and engage your brain – especially by learning new skills – the healthier it will be and the better it will function.

It was recognised more than a decade ago that the same processes that build the neuronal architecture and connectivity during development and adult brain plasticity are also involved in age- and disease-related degeneration of neural circuits (Mattson, 1989), which can manifest in degenerative diseases such as Alzheimer's, Parkinson's, and Huntington's disease.

Perhaps the most amazing recent advance in brain science involves neurogenesis, which is the production of new brain cells. Not long ago, it was widely believed that we are born with all of the neurons we will ever have. This led to the depressing idea that we all slowly go downhill as the brain loses thousands of neurons each day. However, we now know that a healthy 75-year-old brain has just as many neurons as it did when it was going through life in the body of a 25-year-old. Although it is true that the brain loses cells every day, it simultaneously grows new neurons to replace them.

In the 1960s, the emergence of new brain cells was first discovered in the hippocampus, where it was thought that they probably play a role in storing memories (Gould, Beylin, Tanapat, Reeves & Shors, 1999). More recent studies with monkeys have shown that new cells grow in other parts of the brain as well. Each day, thousands of new cells originate deep within the brain and then migrate to the cerebral cortex. Once there, they link up with other neurons to become part of the brain's circuitry (Gould, Reeves, Graziano & Gross, 1999). In other words, the cortex, which is the seat of intelligence, receives a steady stream of new brain cells.

'A closer look: Jog your memory' examines research that could show a link between exercise and brain power.

A CLOSER LOOK

Jog your memory

The health benefits of a regular run have long been known, but scientists have never understood the curious ability of exercise to boost brain power.

Now researchers think they have the answer. Neuroscientists at Cambridge University have shown that running stimulates the brain to grow fresh grey matter and it has a big effect on mental ability.

A few days of running led to the growth of hundreds of thousands of brain cells that improved the ability to recall memories without confusing them, a skill that is crucial for learning and other cognitive tasks, researchers said.

The new brain cells appeared in a region that is linked to the formation and recollection of memory. The work reveals why jogging and other aerobic exercise can improve memory and learning, and potentially slow down the deterioration of mental ability in old age.

The research builds on a body of work that suggests exercise plays a vital role in keeping the brain healthy by encouraging the growth of brain cells. Previous studies have shown that this 'neurogenesis' is limited in people with depression, but that their symptoms can improve if they exercise regularly.

Scientists are unsure why exercise triggers the growth of grey matter, but it may be linked to increased blood flow or higher levels of hormones that are released while exercising. Exercise might also reduce stress, which inhibits new brain cells through a hormone called cortisol.

The Cambridge researchers joined forces with colleagues at the US National Institute on Ageing in Maryland to investigate the effect of running.

They studied two groups of mice, one of which had unlimited access to a running wheel throughout. The other mice formed a control group.

After training sessions, the mice in the exercising group scored almost twice as highly as the other mice in a repeated memory test for a sugar reward, a report in the *Proceedings of the National Academy of Sciences* said. The sedentary mice got steadily worse at the test.

Source: Sample, I. (2010) 'Jog your memory: Brain cell secrets explored.' *The Sydney Morning Herald*. 20 January.

plasticity
The ability of the brain to change its structure and relocate functions to different areas and/or neuronal networks

developmental plasticity
Changes in neurons and synaptic connections that occur as a specific consequence of developmental processes

adaptive plasticity
A term referring to the ability of neurons to alter the connections between the synapses in accordance to best suit the environmental conditions, when learning something new or when re-learning something after brain injury

neurogenesis
The production of new brain cells

CHECK YOUR UNDERSTANDING 5.5

1 Fill in the gaps with the correct terms.
   a The ability of the brain to change its structure is called brain __________.
   b The brain can produce new brain cells – this is called ____________.
   c Following brain injury, the ability of neurons to alter connections between the synapses when learning something new or when re-learning something is called ____________________.
   d The brain's ability to change neurons and synaptic connections as a consequence of growth is known as ____________________.

2 Identify the three circumstances under which brain plasticity can occur.

3 Match each term with its definition.

a	Plasticity	i	The production of new brain cells
b	Phrenology	ii	The ability of the brain to change its structure and relocate functions to different areas and/or neuronal networks
c	Adaptive plasticity	iii	The ability of the brain to adapt to the environment and alter the connections between neurons
d	Neurogenesis	iv	An early attempt to map the bumps on the head and relate them to personality attributes

4 New brain cells were first found in which brain structure?
   A The amygdala
   B The cerebral cortex
   C The hippocampus
   D The brain stem

5 Which of the following is a circumstance in which brain plasticity can occur?
   A When the immature brain organises itself
   B When something new is learnt
   C When brain injury has occurred
   D All of the above

TIMING OF EXPERIENCE: CRITICAL PERIODS

Why do some experiences have more lasting effects than others? Part of the answer lies in the concept of critical periods. These are times of increased sensitivity to environmental influences when the conditions are optimal for certain capacities to emerge in an organism.

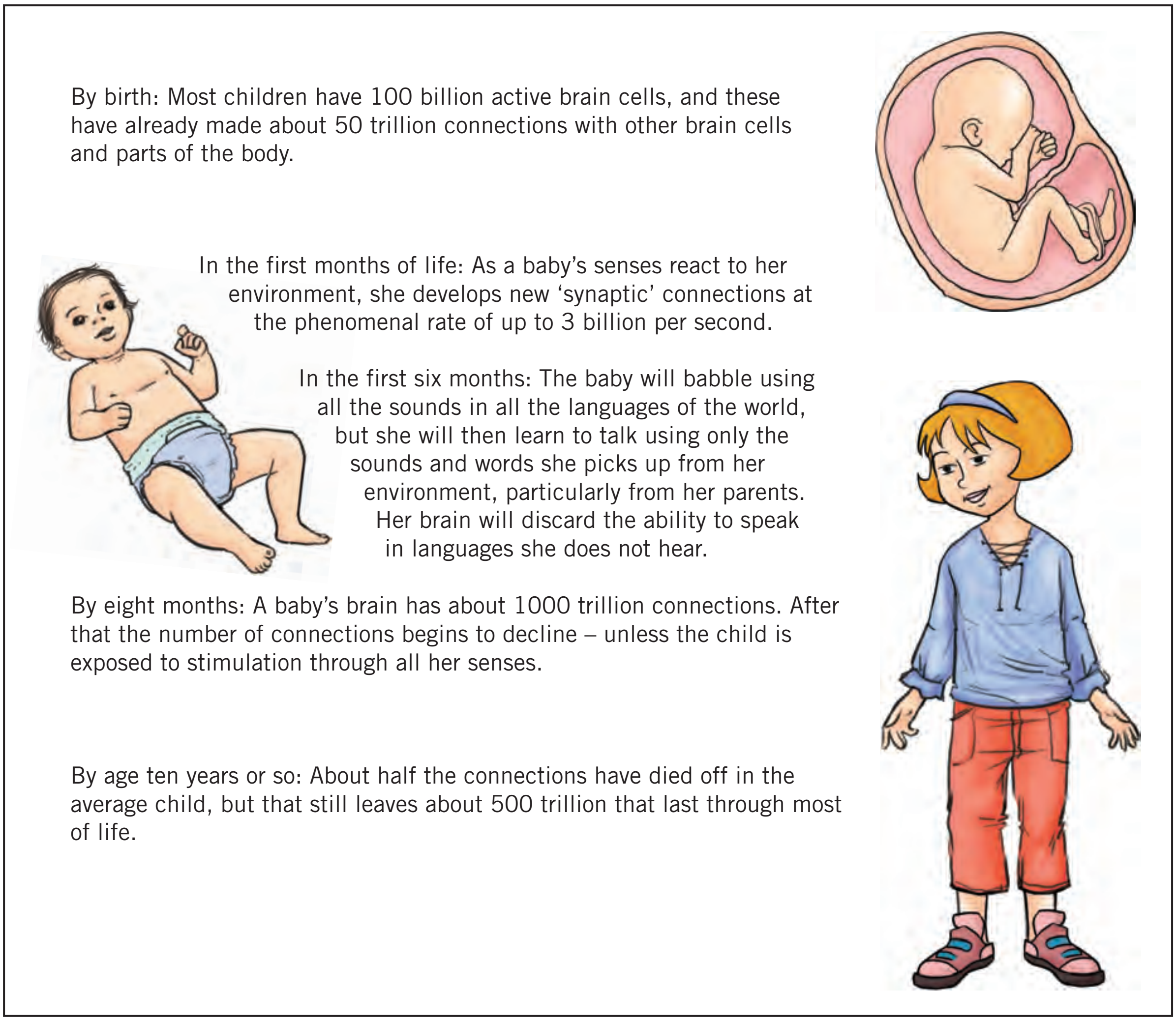
Events that occur during a critical period can permanently alter the course of development (Bornstein, 1989). For example, if a pregnant woman contracts German measles, particularly in early pregnancy, the child may be born with heart defects, cataracts or hearing loss. If the measles were contracted in the later stages of pregnancy, the disease would not cause damage to the baby.

Often, certain events must occur during a critical period for a person to develop normally. For example, within the human nervous system, it appears that different areas of the brain used in learning develop fully at different times. The brain must go through a period of forming synapses and then pruning back unused connections to complete its development. Most of this occurs in the first 12 years of life. The frontal lobe has one of the longest periods of development, taking up to 10 years to develop fully.

Research conducted by Weisel and Hubel in the 1960s showed that if a newborn kitten has its eye stitched shut early in its development (within 4–6 weeks), the kitten will become permanently blind in that eye. However, if the eye is sewn shut later in development (after four months), the kitten will not become blind in that eye. This study led the researchers to conclude that there must be a critical period for vision in kittens, and the neural pathway between the eye and the brain must have visual input to develop properly. If this does not occur, the result will be blindness. We can see that this is an example of the plasticity of the brain, as the connections within the neural pathways rearrange themselves to fit the changed circumstances.

Children do have far more plasticity than adults, which would imply that critical periods are important in development. For example, if severe damage occurs in the left hemisphere of a child's brain before that child is two years old, the brain can shift language processing to the right side of the brain (see Figure 5.10). If the damage occurs between the ages of two and six, new language areas tend to develop

Figure 5.10 Children under the age of two can shift language processing to the right hemisphere if damage occurs to the left hemisphere (the normal location for language centres).



Source: Adapted from www.thelearningweb.net

Figure 5.11 Brain development in the early years of life

in both hemispheres. Such drastic shifts in language processing would be impossible for an adult brain (Mueller et al., 1999).

Some research has hypothesised that the brain is at its most 'plastic' from birth until the age of three (Kotulak, 1996); however, there is no definitive evidence to suggest that this is the case. In fact, there is research to suggest that the brain remains plastic throughout life, and continues to respond to stimulation into old age (Thompson & Nelson, 2001). Functions such as language and vision have been researched in enough depth to provide evidence towards the existence of critical periods for those functions. However, to say that the first three years of life are the *most* critical is misleading. Figure 5.11 shows the major developments of a child's brain from birth up to the age of 10.

'Focus on research: Brain structure changes in the elderly due to training' examines a study of learning in the elderly. 'A closer look: Brain training' examines the effect of brain training in specific and general mental capacities.

FOCUS ON RESEARCH

Brain structure changes in the elderly due to training

Until quite recently, it was generally assumed that the capability of the human brain to modify its structural pattern to fit new environmental demands was restricted to the early stages of development; that is, it was not possible after a specific critical period had passed. Recent studies where researchers have examined the functional reorganisation of cortical maps in various areas of the human adult brain (Weiller et al., 1993; Knecht et al., 1998) have shown, however, that the adult brain is capable of change.

It had been suggested that learning is associated with a temporary and highly selective increase in brain grey matter in healthy young adults. However, it was not clear whether and to what extent the ageing brain is still able to exhibit

Continued

critical period
A time of increased sensitivity to environmental influences when the conditions are optimal for certain capacities to emerge in an organism

such structural plasticity. The purpose of a study by Boyk et al. (2008) was to investigate the adaptive behaviour of the central nervous system to learning to juggle in healthy senior citizens, and to compare these results with those of the same study conducted previously using younger participants.

The participants in the experimental (training) group were 44 individuals (20 male and 24 female) with a mean age of 60 years. The participants had no juggling skills prior to the undertaking of this study.

The training participants were all given three MRI scans. The first scan was taken at the start of the study. Then all participants in the training group received three juggling balls and were instructed on how to learn a three-ball cascade. The target behaviour was to learn to juggle for a minimum of 60 seconds. The participants were then given three months to practise juggling. The second MRI was taken after the three months. The participants were then instructed not to practise their juggling for the next three months, after which time a third scan was taken. Most participants were no longer proficient at juggling by the time the third scan was taken.

Only 23 per cent of the group of elderly jugglers achieved the target of 60 seconds of non-stop juggling. In comparison, 100 per cent of a group of 20-year-olds in a previous study (Draganski et al., 2004), under the same conditions, were able to juggle for a minimum of 60 seconds.

The MRI scans suggested that the human brain, even in old age, maintained its capacity to change its structure according to learning or exercise demands. The brain scans showed grey matter changes in the visual cortex after learning, and transient changes in the left side of the hippocampus.

As the elderly do seem to be capable of plasticity, it may be concluded that their lower percentage in achieving the juggling target was due to physical limitations in carrying out the task rather than limitations in learning ability.

Given that cortical plasticity of the human brain appears to be relevant for elderly individuals, the data supports conclusions about the potential value of exercise for elderly people. As people age, they should not do less, but do more to keep and maintain their physical abilities in order to match their mental capacities.

Source: Adapted from Boyke, J., Driemeyer, J., Gaser, C., Buchel, C & May, A. (2008) Training-induced brain structure changes in the elderly. *The Journal of Neuroscience, 28(28)*, 7031–5.

QUESTIONS

1 What was the aim of this experiment?
2 Who were the participants?
3 What was the procedure?
4 What were the results of the study?
5 What were the conclusions of the study?

A CLOSER LOOK

Brain training

Many brain training products claim to be able to keep us mentally fit. Some products even claim that brain training can prevent dementia in old age. But there is no scientific proof that games or other brain exercises can have this effect. That is what the German Institute for Quality and Efficiency in Health Care (IQWiG) has discovered.

Brain training can lead to an improvement, but only in the specific ability it is aimed at.

As we get older our thinking gets slower and it is harder for us to learn new things. Many people try to stay mentally fit by, for example, learning a new language or doing crossword puzzles. Computer games that aim to keep the brain active are also becoming increasingly popular. 'Doing exercises like trying to find symbols on a computer screen as fast as possible can actually improve your reaction time,' explains Professor Peter Sawicki, the Institute's Director. 'But scientific studies have shown that brain training only leads to an improvement in the specific ability that it is aimed at. So if you learn to find symbols quickly, it does not mean that you will be able to remember names better too.'

There is no need for people to push themselves to do brain training if they do not enjoy it.

Research has not shown that brain training can keep up or enhance people's overall mental abilities. 'So there is no need to feel bad if you do not enjoy brain training: there are no [physical] health reasons for doing it,' says Sawicki. 'But if you think brain training exercises are fun, you can try out different things. For example, completing sequences of letters can improve your logic skills. And practising word-association techniques can help you to remember things better.'

Source: *ScienceDaily* online (2009) 'Brain Training Can Help Improve Specific Abilities in Older People.' 24 December.

EVIDENCE IN SUPPORT OF PLASTICITY

Much evidence supports the theory that when you become an expert in a specific skill, the areas in your brain that deal with that type of skill will grow. For example, the left parietal lobe in the brains of people who are bilingual (people who can speak more than one language) is larger than that of monolingual people. It appears that learning a second language is possible through functional changes in the brain (Mechelli et al., 2004).

Musicians are skilled in performing complex physical and mental operations. These may include skills such as the translation of visually-presented musical symbols into complex, sequential finger movements; using improvisation; recalling memories of long musical phrases; or identifying tones without the use of a reference tone. Playing a musical instrument typically requires the simultaneous integration of a number of sensory and motor functions with sensory feedback mechanisms to monitor performance. Gaser and Schlaug (2003) compared professional musicians (who practise at least one hour per day) to amateur musicians and non-musicians. They found that grey matter (cortex) volume was highest in professional musicians, intermediate in amateur musicians, and lowest in non-musicians in several brain areas involved in playing music. These were the motor regions, anterior superior parietal areas and inferior temporal areas.

Further evidence to support the plasticity of the brain has come from studies on the changes in the brains of students before and after learning for an exam. Draganski and colleagues (2006) showed that extensive learning of abstract information can trigger some plastic changes in the brain. Using imaging techniques, they tested German medical students three months before their medical exam and again immediately after the exam, and compared the images to brains of students who were not studying for an exam at this time. Medical students' brains showed learning-induced changes in regions of the parietal cortex as well as in the posterior hippocampus. These regions of the brain are known to be involved in memory retrieval and learning.

Plasticity can also be observed in the brains of London taxi drivers. See 'Focus on research: "Which way, guvna?"'

Over the past decade, there has been progress in research that has demonstrated evidence of adaptive plasticity. Recent studies have shown that functional and structural changes take place in the cerebral cortex after injury, such as occurs after stroke or trauma. The sensorimotor learning and the cortical injury interact, so that after an injury to the cortex, the structure and function of undamaged parts of the brain can 'take over' the function of the injured brain part. This process takes place during recovery, and can often be influenced by physical rehabilitation interventions (see Figure 5.12). For example, if an individual were to lose the ability to feel their hand due to damage to a particular region of the sensorimotor cortex, then it is possible for the brain to adapt and move the location that registers sensory information about the hand elsewhere on the cortex.

Figure 5.12 A brain injury to this person's motor cortex left him unable to walk. He can learn to walk again because of brain plasticity: the undamaged parts of his brain have taken over the functions of the damaged parts.

Of course, this will not always be the case – the brain cannot recover from all injuries. Rehabilitation is shaped to some extent by the sensorimotor experiences of the individual in the weeks or months following injury.

Some drug therapies have been found to have a positive effect on functional recovery after brain injury. In one study, rats were given amphetamines after injury to the cerebral cortex. This enhanced their motor recovery by increasing the release of specific neurotransmitters involved in the process of movement. In addition, there is some evidence to suggest motor performance of human stroke patients can be enhanced using drug therapy alongside physical rehabilitation (Nudo, 2003).

VIDEO
Neuroplasticity

'Videolink: Neuroplasticity' shows a general presentation on plasticity of the brain.

FOCUS ON RESEARCH 'Which way, guvna?'

Studies into the effects of learning on brain structure have included those by Maguire et al. (2000). They conducted research into the effects of spatial experience on brain structure using London taxi drivers (see Figure 5.13).

London taxi drivers were ideally suited to this study, as they use spatial navigation as an integral part of their job. London taxi drivers must undergo rigorous training, and it takes approximately two years to learn how to navigate the vast city.

The aim of the experiment was to compare the brains of London taxi drivers to participants who did not drive taxis, to see whether there were any structural differences between the brains. The experimental group consisted of 16 male London taxi drivers who were all right-handed, with a mean age of 44 years. All drivers were healthy according to medical, neurological and psychiatric tests. The control group consisted of 50 right-handed males with a mean age of 44 years who were all healthy according to the same tests performed on the taxi drivers.

The brains of all participants were scanned using structural MRI (on the same machine), and the scans were then compared. The results showed that an area of the rear part (posterior) of the hippocampus in the brains of the taxi drivers was significantly larger in comparison to those of the control participants. The control group was found to have a larger area in the front part (anterior) of the hippocampus

Continued

than the experimental group. Taxi drivers with more driving experience showed greater volume in the hippocampus than drivers with less experience (Maguire et al., 2000).

It appears, therefore, that the hippocampus may play a role in storing spatial information regarding navigation and location. As more spatial information is learnt, the hippocampus expands to take this in. The more spatial information or learning that takes place, the larger the volume of the hippocampus appears to become. This has led researchers to conclude that there is a capacity for the human brain to change in structure (increase plasticity) in response to environmental demands.

Figure 5.13 London taxi drivers were found to have a larger posterior area of the hippocampus than non-taxi drivers.

QUESTIONS

1 What was the aim of the experiment?
2 Who were the participants?
3 What were the results?
4 What are three limitations or extraneous variables for this experiment?

Imaging the learning brain

Our senses (touch, taste, hearing, sight and smell) all trigger neural activity in the brain. As we process (learn) new sensory information, new neural connections and pathways are formed and/or existing connections and networks are strengthened. In the past, scientists thought specific forms of sensory information followed the same neural pathways every time, and that these were determined by genetic makeup. However, modern brain imaging technologies such as CT scans, PET scans, SPECT scans, MRI scans and fMRI scans (discussed in detail in chapter 2) provide clear evidence that, during learning, changes occur in neurons that can result in permanent structural and functional changes in the brain.

In addition, these imaging technologies show how specific areas of the brain are involved in different types of activities; thus, they allow researchers to identify localised changes in the brain due to learning specific tasks. For example, when a person attends to a sound, reads a passage or imagines a scene, the activity in specific brain centres changes as a result (Posner & Raichle, 1994).

The exciting recent discovery that the brain can alter its shape and size during a period of weeks as a result of learning new skills has led to valuable new insights on the structural response of the brain to learning and practice. New 'functional' brain imaging techniques allow us to further evaluate brain changes in response to learning, development, disease and also recovery following injury.

The ability to capture images of the brain in action as it is learning is particularly useful in the diagnosis and treatment of brain injuries. Because these technologies provide a clear picture of brain structures at work, doctors can use these brain imaging techniques to determine if a brain-damaged person is aware and engaged in learning. If they determine that they are not, the image provided allows them to target the specific structures or areas of the brain that are contributing to the malfunction.

'A closer look: The powerful tool of simultaneous fMRI and PET imaging' explains how researchers have found a way to compare different measures of the brain by taking simultaneous scans.

A CLOSER LOOK

The powerful tool of simultaneous fMRI and PET imaging

Clinical researchers from the University of Pennsylvania Health System (UPHS) are the first to combine fMRI and PET scanning in radiology, creating a way to compare different measurements of the brain's function concurrently. This analysis could lead to better diagnosis and treatment in patients suffering from brain disorders, like Alzheimer's disease.

'By using these two established methods, we now have an integrated way to look at the brain's functions,' explained Andrew Newberg, MD, a radiologist in nuclear medicine at UPHS and lead author on this clinical study. 'We can now get a more comprehensive view of what's happening in the brain at a particular time, than we've ever been able to do before. We can look at more diseases and more activation states.'

The work combines the functional imaging of fMRI (functional magnetic resonance imaging), which captures the blood flow in the brain, and PET scanning (positron emission tomography), which looks at the glucose metabolism in the brain. 'Normally, these two measures are coupled, or paired together. The more metabolism you have, the more blood flow,' adds Newberg. 'But there are times the two don't match up with each other like with stroke, seizure disorders, or neurodegenerative disorders. That's what led us to this new technique so that we can explore many different aspects of the brain's function.'

So how does this new simultaneous imaging approach actually work? Radiologists inject a patient with radioactive material used for a PET scan *while* the patient is already inside an fMRI scanner. During the time that material is being taken up in the brain, radiologists are acquiring the fMRI image. Then, when that is complete, radiologists take the patient immediately to the PET scanner, to retrieve the PET image.

'We have both machines available to us and have now put them together in a way that works,' adds Newberg. 'We can take the results of the simultaneous fMRI and PET scans and come up with two separate results and compare them for a new look at the brain. Using this technique, you capture the exact same moment in the brain with both scans. It will help to show us what the relationship is between metabolism and blood flow. Do those two really match up in large majority of conditions?'

Newberg said one goal of this new simultaneous fMRI–PET scan is to better understand the effect of certain medications on the brain and body. The clinical research for this study has been conducted through the PET Center at the Hospital of the University of Pennsylvania and through the Center for Functional Neuroimaging (CFN), known for its excellence in multi-disciplinary brain imaging.

Source: *ScienceDaily* online (2005) 'Penn Researchers Discover the Powerful Tool of Simultaneous fMRI and PET Imaging.' 13 October.

CHECK YOUR UNDERSTANDING 5.6

1 A critical period refers to:

A the most important time in the life of an organism.

B cell growth and degeneration over time.

C the optimal time for certain capacities to emerge in an organism.

D All of the above

2 Medical students tested before and after an exam showed increases in the ________ lobe of the brain.

A frontal

B parietal

C temporal

D occipital

3 Fill in the gaps with the correct terms.

a Children have far more plasticity than adults. For example, if the ______ hemisphere is severely damaged, children under the age of two can shift language processing to the right side of the brain.

b The _______ lobe has one of the longer periods of development, taking up to 10 years.

c A time of increased sensitivity to environmental influences when the conditions are optimal for certain capacities to emerge in an organism is called a _______________.

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

a The modern neuroimaging techniques allow researchers to identify localised changes in the brain due to learning specific tasks.

b If learning a skill has not occurred before the critical age of three years old, then the organism will not be able to learn the skill.

c There is no evidence to support brain plasticity.

d The critical period for visual development in kittens appears to be the first four months of life.

e Children have far more plasticity than adults.

f The ability to capture images of the brain in action as it is learning is particularly useful in the diagnosis and treatment of brain injuries.

5 The area of the brain that specialises in acquiring and using complex spatial information in order to navigate efficiently is the:

A amygdala.

B hippocampus.

C hypothalamus.

D occipital lobe.

Chapter summary

WORDCHECK TEST YOURSELF

Learning:

- Learning is a relatively permanent change in behaviour (or behaviour potential) due to experience. It begins at birth and continues throughout our lifetime. It enables us to function on a daily basis and adapt to changes that are constantly occurring in the world around us.

Behaviours not dependent on learning:

- *Reflex action*: A simple, automatic, involuntary response to a specific stimulus that comes directly from the nervous system and is basically the same each time it occurs
- *Fixed action patterns*: The innate predisposition – essentially identical among most members of a species – to behave in a certain way in response to a specific environmental stimulus; also known as species-specific behaviour
- *Maturation behaviours*: Innate, age-related behaviours that result from the physical growth and development of the body, brain and nervous system at fairly predictable ages in the life cycle

Areas of the brain involved in learning:

- While research has established that learning is not confined to a single brain area, studies of individuals who have experienced damage to specific brain structures such as the *cerebellum*, *limbic system* – and areas such as the *frontal lobes* – support the theory that these structures and areas have some involvement in most types of learning.

Synapse formation:

- For learning to occur, neurons need the ability to communicate. The gap between neurons where communication takes place is called the *synapse*.
- *Synaptogenesis* refers to synapse formation. Synaptogenisis occurs throughout a healthy person's lifespan, but it occurs most rapidly during early brain development, beginning at about two months before birth until approximately two years after birth.

Neurotransmitters:

- Neurotransmitters are chemicals released from the pre-synaptic neuron, which cross the synaptic gap to receptor sites on the post-synaptic neuron. These enable chemical messages to travel between neurons and, therefore, throughout the nervous system to the brain and back again.
- Some neurotransmitters have an excitatory effect, and others may have an inhibitory effect.

Brain plasticity:

- The brain has the ability to change its structure and relocate functions to different areas and/or neuronal networks.
- *Developmental plasticity* refers to changes in neural connections during development as a result of environmental interactions as well as neural changes due to learning. Developmental plasticity is specific to the change in neurons and synaptic connections as a consequence of developmental processes
- *Adaptive plasticity* refers to changes in neural connections in response to changing environmental conditions (such as brain injury) as well as neural changes induced by learning.

Critical periods:

- *Critical periods* are periods in the life of an organism, where they are more sensitive to environmental influences so that conditions are optimal for certain capacities to emerge.
- For the human nervous system, it appears that different areas of the brain used in learning develop fully at different periods of time.
- The brain must go through a period of forming synapses and then pruning back unused connections to complete its development. Most of this occurs in the first 12 years.
- The frontal lobe has one of the longer periods of development taking up to ten years.

Imaging technologies:

- Modern brain imaging technologies such as CT scans, PET scans, SPECT scans, MRI scans and fMRI scans (discussed in detail in chapter 2) provide clear evidence that, during learning, changes occur in neurons that can result in permanent structural and functional brain changes.

Apply your knowledge and skills

SECTION A: MULTIPLE-CHOICE QUESTIONS

1 Which of the following is an example of a fixed action pattern?

A A boy blinks when air is blown into his eyes

B A rat repeatedly presses a lever to obtain some food pellets as reward

C A bird gathers small sticks in order to build a nest

D A young girl learns to ride a bike by watching a DVD

2 Which of the following statements is correct?

A A reflex is a learnt behaviour while a fixed action pattern is not.

B A fixed action pattern can occur in any species, while a reflex is species specific.

C A reflex is a simple behaviour, while a fixed action pattern is more complex.

D Humans have many known fixed action patterns.

3 An example of a behaviour acquired through maturation is:
- **A** riding a bike.
- **B** playing tennis.
- **C** singing a song.
- **D** walking.

4 Learning is:
- **A** a change in behaviour that involves reflexes, fixed action patterns and maturation.
- **B** a change in behaviour that is relatively permanent and due to reflex actions.
- **C** a change in behaviour that is due to maturation.
- **D** a change in behaviour that is relatively permanent, as a result of experience.

5 A male lyrebird builds a mound and dances on it to attract a mate. This behaviour is an example of:
- **A** a reflex.
- **B** a fixed action pattern.
- **C** maturation.
- **D** a learnt behaviour.

6 The chemicals involved in passing messages across the synapse are called:
- **A** neurotransmitters.
- **B** neurogenetics.
- **C** excitatory chemicals.
- **D** inhibitory chemicals.

7 Plasticity of the brain refers to:
- **A** the brain's ability to remain stable over time.
- **B** the brain's ability to set like 'plastic' when learning occurs.
- **C** the brain's ability to adapt and change when required.
- **D** the brain's inability to adapt and change when required.

8 The role of the amygdala in learning is related to:
- **A** planning and problem-solving.
- **B** balance and coordination.
- **C** mathematics and language.
- **D** emotions such as aggression and fear.

9 Synapse formation can occur:
- **A** at any time in a healthy person's life.
- **B** only before the age of three years old.
- **C** at any time after the age of three years old.
- **D** only in the womb.

10 The term used to describe the formation of a synapse is:
- **A** differentiation.
- **B** multiplication.
- **C** neurogenesis.
- **D** synaptogenesis.

11 Which of the following technologies are used to image the brain?
- **A** CT
- **B** EEG
- **C** ESB
- **D** All of the above

12 Studies on the brains of London taxi drivers compared to people who do not drive taxis have shown that:
- **A** taxi drivers are more intelligent than other people.
- **B** non-taxi drivers are more intelligent than taxi drivers.
- **C** taxi drivers have more coordination than other types of drivers.
- **D** taxi drivers have a larger region of the hippocampus than non-taxi drivers.

13 Parts of the brain involved in playing music appear to be the:
- **A** motor, temporal and occipital regions.
- **B** motor, temporal and frontal regions.
- **C** motor, parietal and occipital regions.
- **D** motor, parietal and temporal regions.

14 Which lobes of the brain have been found to be larger in bilingual individuals?
- **A** Frontal
- **B** Parietal
- **C** Temporal
- **D** Occipital

15 A relatively recent phenomena that has been discovered is:
- **A** synaptogenesis – neurons can form synapses.
- **B** neurogenesis – the brain can produce new brain cells.
- **C** mitosis – cell separation.
- **D** action potentials – the nerve impulse.

SECTION B: SHORT-ANSWER QUESTIONS

1 Define learning.

2 How do we know that learning has taken place?

3 What are two differences between a reflex action and a fixed action pattern?

4 Define maturation and give an example.

5 Name two of the brain areas involved in learning and the specific types of learning they are involved in.

6 What is involved in the process of synaptogenesis?

7 Outline two of the effects a neurotransmitter may have on the target cell.

8 The human brain is said to be ‘plastic’. What does this term mean when applied to the human brain?

9 There appear to be some ‘critical periods’ in the development of the human nervous system. What is meant by this term? Outline any critical periods that may apply to humans.

10 From your knowledge of brain imaging technologies, which technique would be most advantageous to use if you wanted to see evidence of the human brain ‘learning’?

SECTION C: EXTENDED-RESPONSE QUESTION

Rhonda is a doctor investigating the effect of learning on the brain. To test which area of the brain is responsible for learning different tasks, Rhonda takes a sample of healthy adults and gives them a variety of tasks to do. She uses imaging technologies to identify any localised changes in the brain during and after the tasks.

Discuss a procedure Rhonda may use to obtain her sample of participants, including any ethical considerations she may need to follow. Then advise Rhonda about two imaging technologies she might use and outline their advantages and limitations.

This question is worth 10 marks.

SECTION D: ASSESSMENT TASK

Media response

You are to present a media response in which you must do the following:

1 Discuss the areas of the brain involved in learning and imaging technologies used to identify localised changes in the brain due to learning.

2 Explain how synapses are formed and the role of neurotransmitters in learning.

3 Explain what is meant by the term ‘plasticity’ in regard to the brain and provide evidence in the form of a case study or research of real-life examples to support your explanation.

You can use one of the following forms to present the information:

- Write a news article for a major newspaper
- Write a script for a news report on television/or radio
- Design a multimedia presentation.