CHAPTER

6 Process of memory

KEY KNOWLEDGE

- the multi-store model of memory (Atkinson–Shiffrin) with reference to the function, capacity and duration of sensory, short-term and long-term memory
- interactions between specific regions of the brain (cerebral cortex, hippocampus, amygdala and cerebellum) in the storage of long-term memories, including implicit and explicit memories.

Human memory is not a single 'thing' or process located in one specific area of the brain. Psychologists describe it as consisting of a collection of interconnected and interacting systems, each of which has distinguishable functions and is represented throughout the brain by different neural mechanisms. This means that we do not have *a memory* — we have different *memory systems*.

Despite their differences and the uncertainty about precisely how many memory systems we have, where they are all located and how they interact, human memory operates in a unitary way, as if it were a single system. Although the systems share a common function of storing whatever we learn so that we can retrieve and use it when required, they process and store different types of information in different ways.

Given the amount of information processed by our memory over a lifetime, its accuracy and reliability is remarkable. However, human memory is not perfect. Every moment of our lives is not automatically stored somewhere in the brain as if on DVD, to be filed away for future reference. Often we fail to properly process, store or access information that we need to retrieve and use at a later point in time. And when we retrieve information, it is not always entirely accurate because of the reconstructive nature of memory.

Given the relationship between memory and learning, human **memory** is often defined as the processing, storage and retrieval of information acquired through learning. This is an information processing approach which likens memory to how a computer works. Some psychologists, however, describe memory more simply as the expression of learning. Furthermore, given that a stored memory can be viewed as a neurological representation of prior experience, an increasing number of psychologists are now defining memory with reference to neural processes; for example, as 'an internal record of a prior experience' or 'the capacity of the nervous system to acquire and retain information and skills'.

Psychologists have devised a number of models to describe and explain human memory. These models usually include boxes to represent components and arrows to represent the movement of information from one component to another. Despite their differences, all models typically refer to memory as involving three fundamental processes:

- **encoding:** conversion of information into a usable form so that it can be neurologically represented ('placed') and stored in memory
- **storage:** retention of the encoded information over time
- **retrieval:** recovery of stored information and bringing into conscious awareness for use when needed.

As shown in figure 6.2, these three processes occur in a sequence, interact and are interdependent. Encoding is first because it occurs at the time of learning. It is through encoding that the brain can 'acquire' and represent incoming sensory information in a usable form. How well information is encoded determines how well that information is stored and how efficiently the information can subsequently be retrieved.

Consider a simple physical device intended to aid memory — a shopping list. If it is to be an effective memory aid, you need to write legibly in a language that whoever uses the shopping list can understand. If the list were to get wet, the ink would blur (impaired storage), making it less distinct and harder to read (retrieval). Retrieval would be harder if your handwriting was poor (an encoding–retrieval interaction) and if the writing was smudged (a storage–retrieval interaction) (Baddeley, 2009).

Although many models have advanced understanding of the process of memory, no single model is viewed as having captured all aspects of human memory. However, some models have been more influential than others.

In this chapter we consider the best-known and most widely used model to describe and explain human memory. We then examine specific regions of the brain that are involved in the storage of different types of long-term memories.

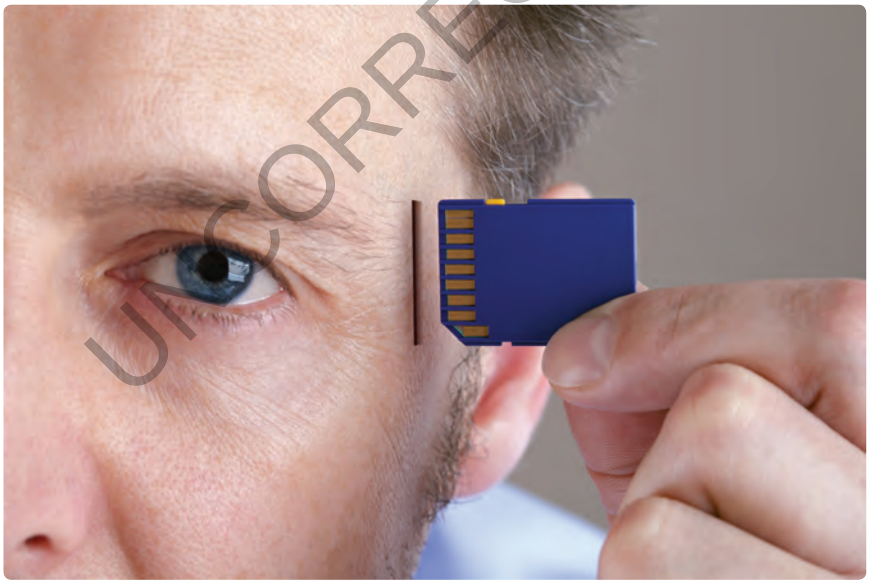

FIGURE 6.1 Human memory is not a single 'thing' or process located in one specific area of the brain.

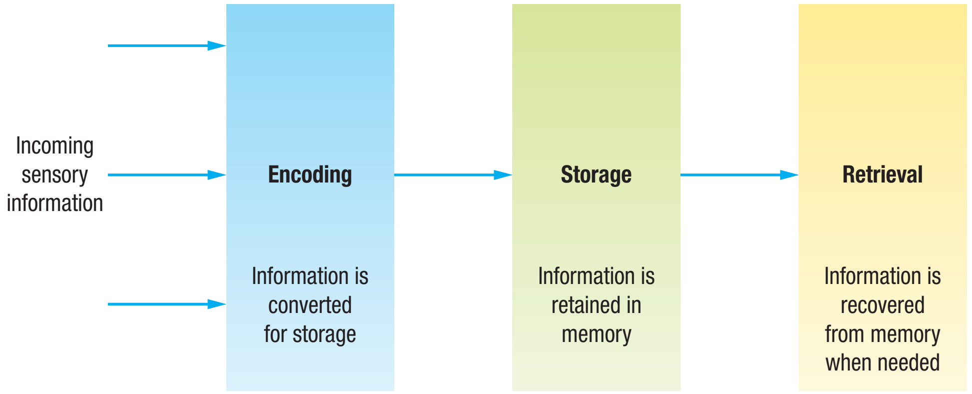

FIGURE 6.2 A simplified representation of the three fundamental processes required for human memory: encoding, storage and retrieval. If any one of these processes fails, memory will fail. Some researchers include *consolidation* as a part of encoding or as a fourth process that enables long-term storage and retrieval.

ATKINSON–SHIFFRIN'S MULTI-STORE MODEL OF MEMORY

In the 1960s, psychology had shifted from the assumption that human memory was a single system towards the idea that two, three or perhaps more memory systems were involved. A very influential model that represented this shift in thinking was proposed by American psychologists Richard Atkinson and Richard Shiffrin in 1968.

The **Atkinson–Shiffrin multi-store model** represents memory as consisting of three separate stores (components) called sensory memory, short-term memory and long-term memory. Each store processes information in different ways and differs in terms of its *function* (purpose and roles), *capacity* (the amount of information it can hold at any given moment) and *duration* (the length of time it can hold information). Despite their distinguishing features, the three stores operate simultaneously and interact in an integrated way.

According to the multi-store model, *sensory memory* is the entry point for new information. It stores vast quantities of incoming sensory information for up to several seconds. If we pay attention to any of the information in sensory memory, it is transferred to short-term memory. Sensory information that is not attended to is lost from memory completely. Information received in *short-term memory* is processed (encoded) and stored for up to about 18–20 seconds, unless a conscious effort is made to keep it there longer. The transfer of information from short-term memory involves a further level of processing (encoding) for storage in long-term memory. Information transferred to *long-term memory* may be stored for up to a lifetime. Information may also be retrieved from long-term memory and brought back to short-term memory when needed. Sometimes, however, we may be unable to retrieve information from the long-term store, which we commonly refer to as 'forgetting'.

The Atkinson–Shiffrin multi-store model also describes memory in terms of its *structural features* and *control processes*. In distinguishing between these, Atkinson and Shiffrin used a computer analogy. They likened structural features to the computer and control processes to the computer programmer who determines the operation of the computer.

Structural features are the permanent, built-in fixed features of memory that do not vary from one situation to another. The three different stores are the basic structural features. Other structural features include the amount of information each store can hold at any given moment (i.e. storage capacity) and the length of time information can be held by each component (i.e. storage duration).

Control processes are selected and used by each individual and may vary in different situations. They are under the conscious 'control' of the individual and which control process is used depends on what the individual does. For example, *attention* is a control process. Whether or not the individual chooses to attend to and select incoming sensory information will determine whether that information is transferred from the sensory store to the short-term store. *Rehearsal* is also a control process and its use determines whether information is retained in the short-term store, how long it will be held there and whether it is transferred to the long-term store. An example of rehearsal is intentionally repeating new information over and over, such as when we try to remember a telephone number. *Retrieval* is a third control process. The specific retrieval method used by the individual will determine whether some or all of the required information in the long-term store will be located, recovered and brought into conscious awareness.

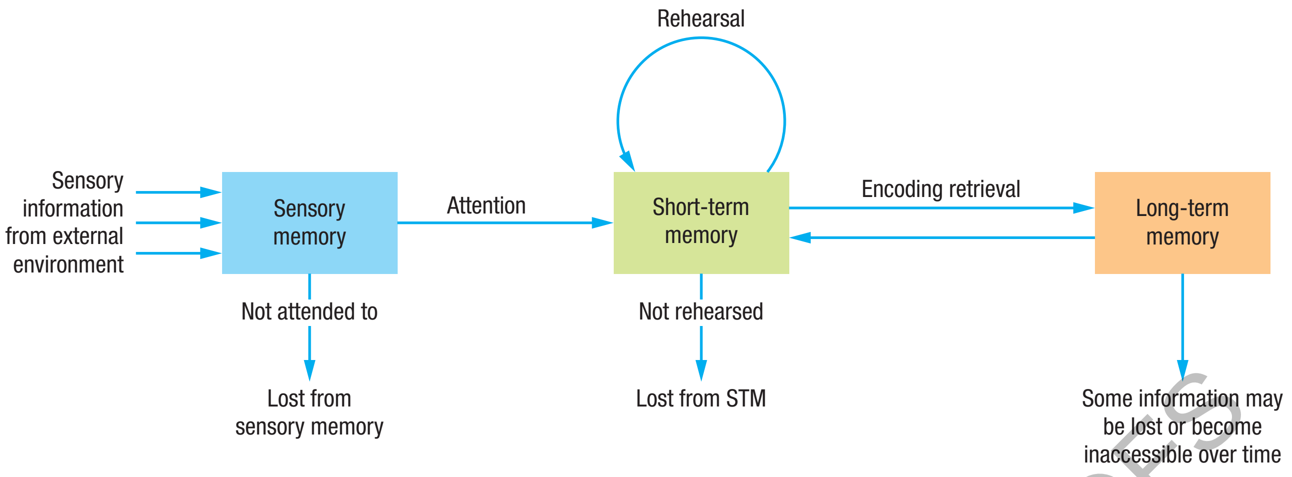

FIGURE 6.3 A contemporary representation of the Atkinson–Shiffrin multi-store model showing the transfer of information through the memory stores

TABLE 6.1 Key features of the three memory stores

Store	Function	Capacity	Duration
Sensory memory (SM)	• Receives sensory information from the environment • Enables perceptual continuity for the world around us	Vast, potentially unlimited	Momentary — about 0.2–4 seconds, occasionally up to 10 seconds
Short-term memory (STM)	• Receives information from SM and transfers information to and from LTM • Maintains information in conscious awareness for immediate use	7 ± 2 pieces of information	• Temporary — 18–20 seconds, occasionally up to 30 seconds • Longer if renewed (e.g. maintenance rehearsal; using for 'working memory')
Long-term memory (LTM)	Information storage for re-access and use at a later time	Vast, potentially unlimited	• Potentially permanent • Some information may be lost or inaccessible over time • Indefinite

LEARNING ACTIVITY 6.1

Review questions

1 How is memory commonly defined in psychology?

2 (a) Describe the processes of encoding, storage and retrieval.
   (b) Explain the interrelationship between these processes with reference to an example.
   (c) Explain whether memory is possible without any one of these processes.

3 Explain the meaning of the term model of memory.

4 (a) What is the Atkinson–Shiffrin multi-store model of memory?
   (b) Give an example of when the different stores could be operating simultaneously and interacting.

5 (a) Distinguish between structural features and control processes in memory, with reference to examples.
   (b) Explain whether each of the following is a structural feature or control process:
      (i) deciding whether retrieved information is correct
      (ii) a neural representation of a memory at a synapse
      (iii) shifting attention from one conversation to another
      (iv) encoding when learning something new
      (v) remembering the answer for an exam question.

6 How might forgetting from each of the following stores be explained in neurological terms?
   (a) STM
   (b) LTM

7 Suggest a biological and a psychological explanation for why we don't remember everything that happens in our lives.

LEARNING ACTIVITY 6.2

Reflection

Some psychologists believe that comparing human memory to information processing by a computer may misrepresent or oversimplify human memory. What do you think?

Sensory memory

In the course of a typical day, thousands of sights, sounds, smells and other stimuli from the external environment bombard your sensory receptors. All this information, whether you pay attention to it or not, is briefly held in sensory memory.

Sensory memory is the entry point of memory where new incoming sensory information is stored for a very brief period. The information received there is assumed to be retained as an exact copy of its original, 'raw', sensory form (rather than in an encoded form). We can store vast amounts of sensory information in sensory memory and it is commonly described as having a vast, potentially unlimited storage capacity.

An important function of sensory memory is that it stores sensory impressions long enough for each impression to slightly overlap the next. This helps ensure we perceive the world around us as continuous, rather than as a series of disconnected visual images or disjointed sounds. To test this, quickly wave a pen back and forth in front of your face. You should see the fading image trailing behind the pen. This is assumed to be an example of your visual sensory memory at work. It seems as if our visual sensory memory momentarily stores a snapshot of the image, then replaces it with another overlapping image.

Sensory information remains in sensory memory just long enough for us to attend to and select the information to be transferred to short-term memory (STM) for processing. It is therefore a *temporary* storage system for information that may subsequently undergo further processing.

We are not consciously aware of most information in our sensory memory. Nor can we consciously manipulate it or extend the time it is retained there. However, when we direct our attention to information in sensory memory, this has the effect of transferring it to STM where we become consciously aware of it. For example, if your attention is focused on reading this page, you will be unaware of many of the sounds around you. Although this auditory information is received by your sensory memory, it is not until you direct your attention to the sounds that you become aware that this information was initially 'registered' in your sensory memory.

FIGURE 6.4 If you walked through the Melbourne CBD during peak hour, your senses would be bombarded by millions of different sights, sounds, smells and other stimuli. These would initially be received in your sensory memory.

It is assumed that any stimulus received in sensory memory is available to be selected for attention and processing in STM. For example, all the objects in your visual field and all the sounds loud enough for you to hear are available for transfer to STM at any given moment. If the sensory information is not attended to and no further processing occurs, its impression fades and therefore cannot be transferred to STM or subsequently to long-term memory (LTM), and is permanently lost from experience.

Incoming sensory information is assumed to be stored in separate sensory systems called *sensory registers*, each of which retains sensory information for different periods. Many psychologists believe that there probably is a separate sensory register for each of the senses. For example, the numerous visual images you process while at a nightclub will be stored in your visual sensory register (called *iconic memory*), while the sounds of music and voices of people will be stored in your auditory sensory register (called *echoic memory*).

FIGURE 6.5 If you went to a popular nightclub, your senses would be bombarded by hundreds of different sights, sounds, smells and other stimuli. These would initially be stored in separate sensory stores called sensory registers. Psychologists believe that there is a separate register for each of the senses.

Iconic memory

The term **iconic memory** is used to describe visual sensory memory — the brief sensory memory for incoming visual information. We usually retain visual images in their original sensory form in iconic memory for about a third of a second. However, they last just long enough to recognise and process the sensory information.

To experience iconic memory, close your eyes for a minute. Near the end of the minute, hold your hand about 25 centimetres in front of your eyes. Then open your eyes and rapidly close them again. You should see an image of your hand that fades away in less than a second (Ellis, 1987).

When you go to the movies, you see what appears to be a continuous scene in which people, animals and objects move quite normally. What is actually presented to your eyes, however, is a series of individual still images, interspersed with brief periods of darkness. In order to see a continuously moving image it is necessary for your visual system, which includes iconic memory, to store the information from one frame until the next frame is presented (Baddeley, 1999).

FIGURE 6.6 (a) Without iconic memory, your world would disappear into darkness during each eye blink. (b) However, if iconic memory did not clear quickly, multiple sensory memory representations of a scene would overlap and distort your perception of the world.

BOX 6.1

Research demonstrating iconic memory

American psychologist George Sperling first demonstrated the existence of a sensory register for visual sensory information in a series of well-known experiments. Sperling (1960) used stimulus materials comprising sets of letters arranged in patterns such as that shown in table 6.2.

< Keyed table 6.2 >

TABLE 6.2

G	K	B	L
M	V	X	P
R	W	Z	C

Sperling projected the sets of letters on a screen for about one-twentieth of a second. He chose this amount of time because it is too brief for any eye movements to occur during the presentations of the letters. The participants were required to verbally report as many of the letters as they could recall. Most could recall only four or five letters in each set no matter how many letters they were shown. Sperling found that with such short exposure, reporting all the letters in a set was impossible.

However, most of Sperling's participants reported that, for an instant, they had seen *all* the letters that had been briefly flashed on the screen. But, by the time they could say four or five of them, the image of the remaining letters had faded. Sperling reasoned that all letters in each set were seen because they had been initially registered in some way and should therefore all be available for a brief time. But because the image disappeared so quickly, only a few letters could be named before they were lost from iconic memory.

To test whether all the letters were actually retained in iconic memory, Sperling conducted a further experiment in which he sounded a tone just after a pattern of letters was flashed on the screen. On hearing a high tone, the participants were told to report only the letters from the top row, on a medium tone the middle row, and on a low tone the bottom row (see table 6.3). Under this condition of the experiment, the participants had to select a line from the visual image they held in iconic memory.

< Keyed table 6.3 >

TABLE 6.3

G	K	B	L	High tone
M	V	X	P	Medium tone
R	W	Z	C	Low tone

Once participants learned this partial report procedure, they were able to repeat any row of letters with about 75% accuracy. For example, after seeing a pattern of letters flashed on the screen, they would hear the medium tone, direct their attention to the middle line of letters in their iconic memory and 'read them off' with considerable accuracy on most trials.

These results indicated that an image of all the letters (i.e. the whole pattern) had been momentarily stored in iconic memory *after* the pattern left the screen. By delaying the tone for longer and longer intervals (from about one-tenth of a second to 1 second), Sperling was able to determine how quickly images in iconic memory fade. As the time-delay lengthened, Sperling found that a participant's ability to recall letters in a designated row declined more and more. Subsequent research by other psychologists has found that the typical duration of iconic memory is about 0.2–0.4 seconds (Cowan, 1995).

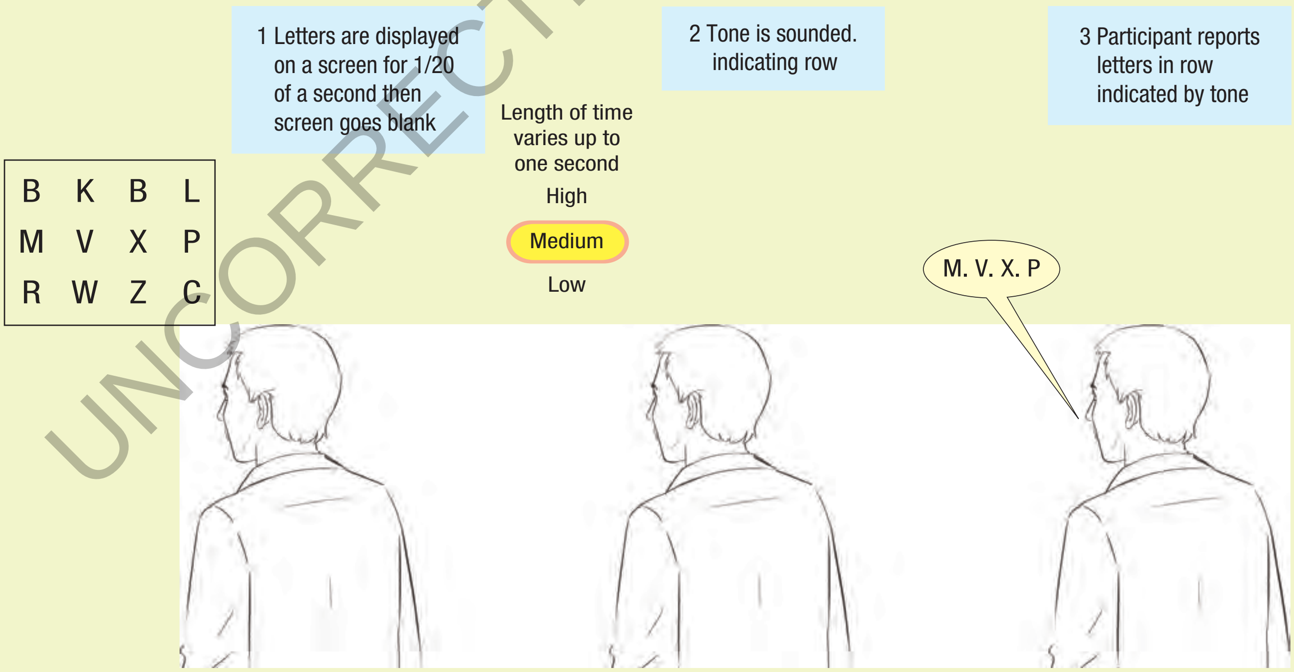

FIGURE 6.7 Sperling's (1960) experimental procedure to investigate the duration of iconic memory

LEARNING ACTIVITY 6.3

Evaluation of Sperling's (1960) research on iconic memory

Consider Sperling's (1960) experiment on iconic memory summarised in box 6.1 and answer the following questions.

1. Name the type of experimental research design.
2. Identify the operationalised independent and dependent variables.
3. Formulate a research hypothesis that could have been tested by the procedures used in the experiment.
4. Briefly state the results obtained.
5. Briefly state a conclusion based on the results obtained.
6. Comment on the extent to which the results can be generalised.

BOX 6.2

Photographic memory

Some individuals are able to recall highly detailed scenes as if the actual event were occurring before them. People who are unusually good at this task are said to have *eidetic memory*, popularly referred to as 'photographic memory'. *Eidetic memory* is the ability to remember with great accuracy visual information on the basis of short-term exposure. Eidetic memories involve eidetic images.

An *eidetic image* is an exact replica of a visual image that persists over time without distortion. People who have eidetic memory are so good at maintaining an image that they literally 'see' the relevant page of a textbook as they recall the information during an exam.

Eidetic images can apparently last for prolonged periods — sometimes days or even weeks — and seem to contain all the information in the original experience. Eidetic images occur most often during childhood (in about 5% of children tested), but are less frequent in adolescence, and are very rarely reported in adulthood (Hilgard, Atkinson & Atkinson, 1979).

In one of the original experiments on eidetic memory, English schoolchildren were shown a complicated street scene displayed in the form of a storybook picture for 35 seconds and then withdrawn from view. Some of the children were able to describe this scene as if describing the information with the actual picture in front of them. A few of these children (who, it would seem, had eidetic memories) could spell out the name of a street that had appeared in the picture even though the street name was a 13-letter German word and the children knew no German (Allport, 1924).

Contrary to popular belief, 'memory experts' generally don't have eidetic memory. Their skill is usually in organising material in memory using mnemonic ('memory-improving') techniques rather than storing information as long-lasting visual images.

Look at the picture in figure 6.8 for about 30 seconds, then answer the questions on page <10>.

FIGURE 6.8

LEARNING ACTIVITY 6.4

Reflection

Is it possible that photographic (eidetic) memory is a long-lasting version of the iconic memory that we all have? What do you think?

Echoic memory

The term **echoic memory** is used to describe auditory sensory memory — the brief sensory memory for incoming auditory information. Echoic memory registers and retains all kinds of sounds, such as speech, the barking of a dog, and the sirens of emergency vehicles. It is called echoic memory because sounds linger in it like an echo. To experience echoic memory, clap your hands once and notice how the sound remains for a very brief time and then fades away.

Studies of echoic memory indicate that it functions like iconic memory, storing sounds (rather than visual images) in their original sensory form. Apart from the sensory register involved, the main difference between iconic and echoic memories seems to be the length of time it takes for information to fade. Echoic memory stores information for longer periods than does iconic memory — typically 3 or 4 seconds — while visual information is retained in iconic memory for an average of 0.3 of a second.

< Keyed table >

TABLE 6.4 Storage duration of iconic and echoic memories

iconic (visual) memory	about 0.2–0.4 of a second
echoic (auditory) memory	about 3–4 seconds

Although the retention period is brief, the availability of auditory information for 3 or 4 seconds is generally long enough to select what has been heard for further processing and interpretation before the sound disappears completely. Consider the times when your attention has been focused on a book you are reading or a television program you are watching and someone asks you a question. Often you are aware they are speaking, but since your attention is focused elsewhere, you do not immediately comprehend the message. However, within a couple of seconds you say 'What?' and then answer the question before the person has time to repeat it. It is believed that because the sound of the original question is held in echoic memory for a few seconds, when you directed your attention to what the person said, the information was then passed on to STM where it was processed and interpreted. The tail-end of the question was temporarily stored in echoic memory while earlier parts of the incoming message were being processed. The response of 'What?' may have occurred just before the last bit of the message in echoic memory was transferred to STM where it became a complete message in conscious awareness.

FIGURE 6.9 Echoic memory stores information for a longer duration than iconic memory. If you hear this bird's squawk, your echoic memory will retain the auditory information for about 3 to 4 seconds. However, if you see a photograph of this bird flashed on a screen for a split second, your iconic memory will hold the visual information for about one-third of a second.

The relatively longer duration of echoic memory is important for understanding speech. You perceive speech by blending successive spoken sounds you hear. When you hear a word pronounced, you hear individual sounds, one at a time. You cannot identify a word until you have heard all the sounds that make up the word, so auditory information must be stored long enough for you to receive all the sounds involved. For example, if someone says 'compare', you will think of judging something against something else, but if someone says 'compute', you will think of something completely different. The first syllable you hear (*com*) has no meaning by itself in English, so you do not identify it as a word. However, once the last syllable is heard, you can put the two syllables together, recognise the word and give it meaning. If echoic memory storage were as brief as iconic memory storage, speech might sound like a series of separate, distinct sounds instead of meaningful words, phrases and sentences.

Findings from the results of various experiments suggest that although sensory memory can store virtually all the information provided by our sensory receptors, this information fades rapidly (with the rate varying among the senses). Information is lost and replaced so rapidly in the sensory registers that we are rarely aware of our capability for retaining sensory information.

Considering the many trillions of bits of information detected by our senses in a lifetime, if we processed everything that reached sensory memory, it would probably lead to confusion, frustration and inefficiency in daily living. For example, when walking through the Melbourne CBD, your echoic memory will register thousands of different sounds but you will attend to and remember only a select few. While crossing Flinders Street, if you hear the screech of car brakes nearby, you will probably pay attention to and act on that information because of the potential threat to your safety. At that moment when you are attending to and processing the sound of the screeching brakes, you will ignore many other sounds that enter echoic memory, such as people talking, the clicking sound of the traffic lights, the sound of a tram bell or that of a bus departing. It would be chaotic and even dangerous at times if we attended to all of the sensory information detected by our receptors.

When you attend to information in sensory memory, it is transferred to STM. Only the information selected for transfer to STM is encoded and has a chance of being stored permanently. Information in sensory memory that is not attended to is lost very quickly — usually within seconds.

FIGURE 6.10 Echoic memory is important for speech comprehension.

BOX 6.2 QUESTIONS

Look at the picture in figure 6.8 on page 8 for about 30 seconds, then answer the following questions.

1. What colour is the girl's dress?
2. Where are the girl's arms?
3. Is the cat looking to its right or its left?
4. How many red flower 'spikes' are there?
5. What colour is the girl's hair?
6. How many stripes are there on the bottom of the girl's dress?

If you correctly answered all these questions, then you may have eidetic memory.

FIGURE 6.11 Selective attention helps ensure the huge amount and variety of incoming information that reaches sensory memory is filtered to keep out irrelevant and unimportant information.

BOX 6.3

Déjà vu

You arrive somewhere for the first time when suddenly you have a weird feeling that you've been there before. This is called déjà vu (French for 'already seen'). In psychology, *déjà vu* is described as the brief and intense feeling that something happening now has happened before in exactly the same way, but without you being able to recall exactly when or where.

Some people believe that déjà vu is evidence of psychic or paranormal experiences, reincarnation or even dreams coming true, but there is no scientific evidence supporting any of these views.

How common are déjà vu experiences? After analysing the results of more than 30 studies on déjà vu that used the survey method, American psychologist Alan Brown (2004) found that about two-thirds of individuals (68%) reported having had one or more déjà vu experiences in their life. He also found that the incidence of déjà vu steadily decreases over the lifespan.

Young adults in the 20–24 years age range tend to have the highest yearly incidence, averaging almost three déjà vu experiences per year. By the time people reach their early forties, they are averaging less than one déjà vu per year. However, a small minority of people seems to be especially prone to déjà vu experiences: about 16% claim to have a déjà vu experience about once a month.

FIGURE 6.12 'Haven't I been here before?'

According to Brown (2003), a typical déjà vu experience is triggered by some kind of visual scene, and the intense feelings of familiarity last for just a few seconds. Déjà vu experiences are most common when people are feeling fatigued or emotionally distressed, in the evening and in the company of others rather than alone. Well-educated people and people who travel frequently tend to have a higher incidence of déjà vu experiences (Hockenbury & Hockenbury, 2006).

Many scientific explanations have been proposed for déjà vu. These include inattentional blindness and memory malfunction. For example, according to the inattentional blindness hypothesis, déjà vu experiences can be produced when you're not really paying attention to your surroundings. When you do focus your attention on the situation a split second later, those surroundings are suddenly perceived as familiar but you cannot quite work out why.

LEARNING ACTIVITY 6.5

Review questions

1. What is sensory memory?
2. Distinguish between the terms sensory memory and sensory register.
3. Why can sensory memory be described as a memory system or sub-system rather than a perceptual system?
4. (a) Define iconic memory and echoic memory with reference to relevant examples.
   (b) Describe the main distinguishing characteristics of iconic and echoic memory. Refer to the type of sensory information received, storage duration and storage capacity.
5. In what way might sensory memory have an adaptive function and assist us in adjusting to ongoing environmental change?
6. Is information in sensory memory subject to an encoding process? Explain your answer.
7. (a) What is required for information to transfer from sensory memory to STM?
   (b) What happens to information that is not transferred to STM?

Short-term memory (STM)

Short-term memory (STM) is a memory system with limited storage capacity in which information is stored for a relatively short time, unless renewed in some way. STM stores information temporarily, but for a longer time than sensory memory (and less than LTM). In STM, the information is no longer an exact replica of the sensory stimulus, but an encoded version.

When you pay attention to information in your sensory memory (or to information retrieved from LTM), the information enters your STM. For example, because you are paying attention to this sentence, it has now entered your STM. In contrast, other information in your sensory memory, such as the feeling of your socks against your skin, did not enter your STM until you directed your attention to it. STM holds all the information you are consciously aware of at any moment in time. Consequently, STM has been described as the 'seat of conscious thought' — the place where all conscious perceiving, feeling, thinking, reasoning and other mental processes take place.

Duration of STM

Generally, most types of information can be retained fairly well in STM for the first few seconds. After about 12 seconds, however, recall starts to decline and by about 18 seconds almost all of the information disappears entirely if it has not been renewed in some way. A commonly used method of renewal is continual repetition (called *maintenance rehearsal*).

FIGURE 6.13 When you have to wait for a while to make a point in a conversation, the information you wanted to share may fade from your STM if the waiting time is more than about 18 seconds.

Some research findings indicate that information can occasionally linger in STM for up to 30 seconds so STM duration is sometimes described as 'up to 30 seconds'.

The best-known and most influential experiment on the duration of STM was conducted by American psychologists Margaret Peterson and Lloyd Peterson (1959). Participants were given 'trigrams' (meaningless groups of three letters such as *qlg*, *jfb* and *mwt*) to memorise. Immediately after the trigrams were presented, the participants were given a distracter, or interference task, requiring them to start counting backwards by threes from an arbitrary three-digit number; for example, '634, 631, 628, . . .'. This was done to prevent practice of the trigrams. Following a time interval that varied from 3 to 18 seconds, a light was used to signal that participants were required to recall the trigrams.

As shown in figure 6.14, the longer the interval, the less likely a participant was able to accurately recall the trigrams. By 18 seconds after the presentation of the trigrams, participants had forgotten almost all of the trigrams. When participants did not have to count backwards, their performance was much better, possibly because they were practising or repeating the items to themselves.

Similarly, if you repeat a phone number over and over to yourself, it can be retained in STM indefinitely. But if someone tells you their phone number and you are then distracted by something else that requires your attention, you are likely to forget the number almost immediately. The distraction not only prevents rehearsal, resulting in loss of the information, but the new information acquired when distracted may exceed the limited capacity of STM and displace, or 'push out', the number from STM, thereby causing you to forget it.

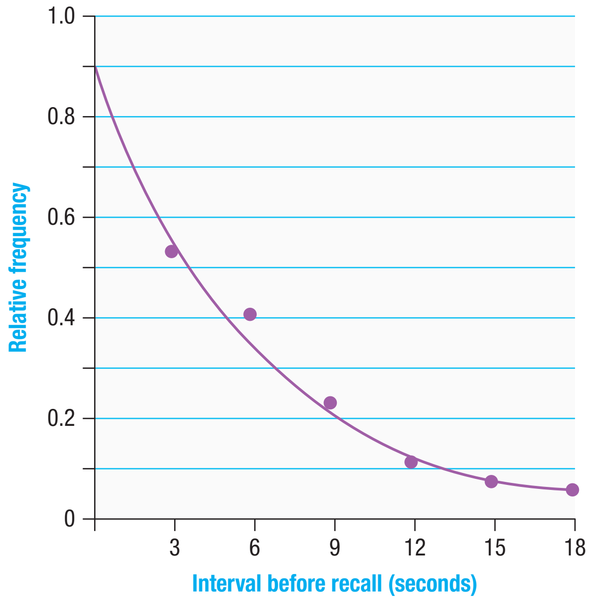

FIGURE 6.14 Peterson and Peterson (1959) demonstrated that information is retained in STM for about 18 seconds. This time frame continues to be widely described as the approximate duration of STM.

Capacity of STM

Compared to sensory memory and LTM, STM has a very limited storage capacity. The amount of information it can hold at any one time is about seven 'bits of information'. This was first described by American psychologist George Miller (1956) in a journal article called 'The magical number seven, plus or minus two'. Miller reached this conclusion after analysing the results of many research studies showing that STM has a capacity of between five and nine units of information at any given moment. Some individuals have a smaller or larger STM capacity. More recent studies have found that Miller may have over-estimated STM capacity.

Estimates of STM capacity are obtained by asking research participants to memorise simple lists of data of different lengths; for example, randomly ordered numbers, letters, nonsense syllables or unrelated words (Miller, 1956). Research in non-western cultures using Chinese characters has also shown a STM capacity of 7 ± 2 pieces of information (Yu et al., 1985).

When STM is 'full', new items can only be added by pushing old items out (see figure 6.15). Space in STM is also filled when we think and when information is temporarily retrieved from LTM to be used or updated. This is one reason why you cannot remember the phone number you have just looked up if you begin thinking about what you might say before you dial the number. You can check your STM capacity by completing the digit span task in learning activity 6.6.

Information stored in STM is lost primarily through *decay* (not being used) and *displacement* (being pushed out) by new information (Reitman, 1974). Decay of information in STM occurs when information is not renewed (e.g. through repetition) and simply fades away with the passage of time. For example, this occurs when you forget what you want to say in a conversation while you wait for another person to finish what they are saying. Your thoughts quickly fade from STM because listening to what the speaker is saying prevents you from repeating the information and therefore maintaining in STM the point you wanted to make.

Displacement of information from STM was demonstrated in research in which participants called a telephone directory assistance service and requested a long-distance telephone number. They showed poorer recall of the number if the person providing the information said 'have a nice day' after giving the number than if they said nothing. The researchers concluded that the friendly message had displaced the phone number from STM (Schilling & Weaver, 1983).

When you think, your 'working space' in STM is used up. The limited capacity of STM explains why it is difficult to think about problems involving more than 7 ± 2 issues (or 'items' of information). We forget some aspects of the problem because they exceed the capacity of STM.

Similarly, fading or displacement can explain the experience of forgetting someone's name straight after they have been introduced to you. If you engage the person in a conversation, the lack of opportunity for 'rehearsal' of their name can result in fading from STM. Furthermore, the new additional items of information introduced during the conversation may result in the capacity of STM being exceeded and displacement of the person's name.

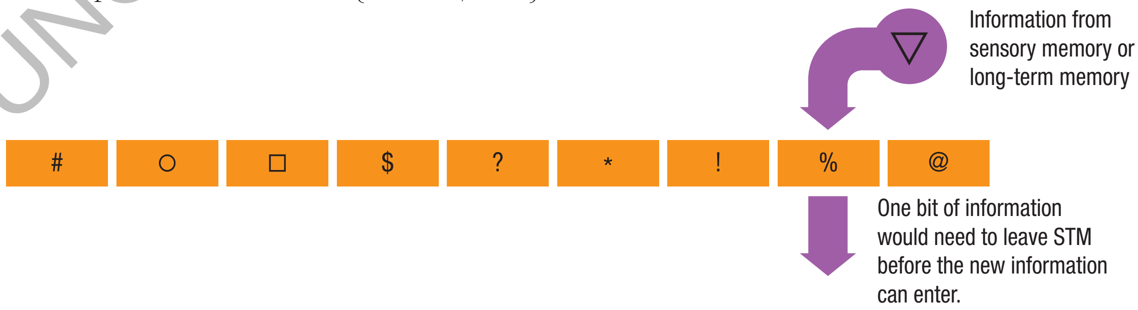

FIGURE 6.15 When STM is 'full', new items can only enter though displacement — by pushing an old item out.

FIGURE 6.16 STM has a storage capacity of 7 ± 2 bits of information. This shopper probably needs a written list to remember all the items she wants to buy unless she uses a strategy that can overcome the limited capacity of STM.

LEARNING ACTIVITY 6.6

Measuring STM capacity using a digit span test

Using a piece of paper (or some other object), cover all the numbers below. Then, progressively move the paper to uncover each row of numbers, one row at a time.

Read the first set of numbers, cover it up, then write the numbers down in their correct order. Repeat this procedure until you reach a row where you begin making errors.

The longest string you are able to reproduce without error is your STM digit span.

9 1 5
3 7 2 4
8 6 9 7 3
1 9 2 8 0 5
4 8 2 6 3 9 1
2 5 3 9 6 0 8 7
5 8 9 5 1 6 9 0 2
7 2 9 6 1 0 9 4 3 6
6 9 4 0 5 8 1 7 2 5 8
2 0 8 4 1 9 7 6 3 2 7 5

BOX 6.4

Chunking

We can get around the limited capacity of STM. One way is to learn information well enough to transfer it to LTM, which probably has an unlimited storage capacity. Another way is to put more information into each of the 7 ± 2 units that can be stored in STM. To illustrate this, read the sequence of letters below:

W N V D C E I V D C S V

Now close your eyes and try to repeat the letters aloud in the same order. Unless you have an exceptional STM, you probably could not repeat the whole sequence correctly. Now try this sequence of letters:

N S W V I C V C E D V D

People usually recall more of the second sequence, even though it is made up of exactly the same letters. The increased ability to recall the second letter sequence demonstrates chunking.

Chunking is the grouping, or ‘packing’, of separate bits of information into a larger single unit, or ‘chunk’, of information. The first sequence of letters was probably perceived as 12 separate items, which probably exceeded your STM capacity. The second letter sequence can be perceived as four ‘chunks’ — NSW, VIC, VCE, DVD — which is within the capacity of STM and is therefore more likely to be remembered. Note also that these chunks are more meaningful, which makes them easier to remember than the nonsense single units comprising a single letter. Meaningful units are easier to remember because they are based on information we already know.

Chunks can take many forms. They can be numbers, images, words, sentences, phrases or abbreviations (such as AFL, RACV or VCAA). Some waiters pride themselves on being able to remember orders of large groups of people without using a notepad, which they do by chunking the information. We also find it easier to remember numbers in chunks (319–528–7451) than as a string of single digits (3195287451). This is why phone numbers, credit card numbers, tax file numbers and other long strings of numbers (or letters) are typically broken up and organised in groups.

FIGURE 6.17 Chunking shows that we can increase the capacity of STM, just as repetition (rehearsal) shows that we can increase the duration of STM storage. (a) Some waiters chunk information to remember big orders without using a notepad. (b) Interpreters must store long and often complicated segments of speech in STM while checking LTM for equivalent expressions in the language they are translating into. This task is assisted if the speaker’s words are chunked into phrases or sentences.

< AQ: Please check and suggest if there are two separte part of figue 6.17 >

STM functions as working memory

Many psychologists now prefer to use the term *working memory* instead of STM to emphasise the active processing and use of information that occurs there. Generally, it is believed that the term 'short-term memory' understates its roles and importance, not only in human memory, but also in our conscious experience of the world and our ability to function effectively in everyday life.

As our 'working memory', STM enables us to actively 'work on' and manipulate information while we undertake our everyday tasks. Information from sensory memory is processed in working memory and information is retrieved from LTM to be used and manipulated in working memory.

Often, we combine information from sensory memory and LTM to perform all kinds of mental activities in our short-term 'working' memory. Interpretation of emotions and feelings, language comprehension, daydreaming, creativity, problem-solving, analysing, reasoning, planning and decision-making all involve 'working memory'. For example, when you think about past events, such as who you shared a cabin with at the last school camp you attended, or when you mentally add the numbers 17 + 5 + 12, the information is temporarily held in 'working memory' while it is being used. Your 'working memory' enables you to read by holding words from the beginning of a sentence while you continue to process the rest of the sentence. Thus, 'working memory' provides a temporary storage facility and mental 'workspace' for information currently being used in some conscious cognitive activity (Baddeley, 1999).

In both the language and the arithmetic examples, temporary storage of information was needed in order to perform some other task — in these examples, understanding and calculating. Information only remains in 'working memory' while we consciously process, examine or manipulate it. Once the required task has been achieved, the information stored there is no longer required and is either transferred to LTM or discarded.

FIGURE 6.18

LEARNING ACTIVITY 6.7

Review questions

1 Define short-term memory (STM).

2 (a) Give an example of an experimental research procedure that could be conducted to test the storage duration of STM.
  (b) Propose a research hypothesis for the experiment.
  (c) How could you temporarily extend the duration of your STM?

3 (a) Give an example of an experimental research procedure that could be conducted to test the capacity of STM.
  (b) Formulate a research hypothesis for the experiment.
  (c) Suggest an example of a strategy that could be used to increase the capacity of STM and explain why this strategy would actually increase the number of items that could be retained in STM at any given moment.

4 In what ways is STM like sensory memory and unlike sensory memory?

5 (a) Distinguish between sensory memory and STM with reference to conscious awareness.
  (b) Explain why STM can be described as the 'seat of consciousness' but neither sensory memory nor LTM can be described in this way.

6 Explain, with reference to an example, why STM may be described as working memory.

7 In what two ways is information most commonly lost from STM?

8 You walk from one room to another to pick something up, and when you arrive you have forgotten why you went to the room. You realise that you were thinking about something else and this made you forget the reason for being in the room. Explain why this forgetting occurred in terms of STM capacity and duration.

LEARNING ACTIVITY 6.8

Reflection

Is 'short-term memory' or 'working memory' the more appropriate term to describe the memory system that receives information from both sensory memory and LTM? What do you think? Which term better reflects capacity? function? Suggest a possible alternate term and explain why it could be a better term.

Long-term memory

Long-term memory (LTM) stores a potentially unlimited amount of information for a very long time, possibly permanently. LTM is not considered to be a single store for all kinds of information. Different types of LTM are associated with different kinds of information and memory processes.

As shown in figure 6.19, the two main LTM types are called explicit and implicit memory, each of which has two or more sub-types. Generally, explicit and implicit memory differ in terms of the way information retrieved from memory is expressed; that is, with or without conscious awareness. Each of these memory types is associated with distinctive neural mechanisms and operates relatively independently of one another. Many psychologists consider them to be separate sub-systems of LTM, processing different types or aspects of information but interacting when required (Schacter, 1992).

Psychologists first identified explicit and implicit memory when reviewing the results of studies with patients who had amnesia due to brain damage. It was found that some could demonstrate implicit memory but not explicit memory, thereby suggesting two memory types, each of which was associated with damage to different brain areas or structures (Graf & Schacter, 1985).

Explicit memory

Explicit memory involves memory that occurs when information can be consciously or intentionally retrieved and stated. Consequently, it is a process that is commonly described as 'memory with awareness'.

Explicit memories can involve words or concepts, visual images, or both. Remembering someone's name, a password, a phone number, the colours of the Italian flag or when a pet died are all examples of explicit memory. You would also rely on explicit memory when identifying a type of flower, explaining a statistics formula to someone, remembering what you ate for dinner last night and whenever you recall a happy or sad event from some time in the past. When explicit memory is used, there is a deliberate and conscious attempt to retrieve previously stored information.

Explicit memories are also called *declarative memories* because, if asked, we can consciously retrieve the information and can 'declare' (state) or 'explicitly' (openly) express it.

The most commonly used tests of explicit memory involve recall and recognition. A prominent feature of these tests is that they refer to and require conscious retrieval of specific information that the individual being tested knows they have previously learnt.

Explicit memory has two sub-types that are commonly called episodic memory and semantic memory.

Episodic memory

Episodic memory is the memory of personally experienced events. These memories often include details of the time, place and our psychological and physiological state when the event occurred. Episodic memory therefore makes it possible for us to be consciously aware of an earlier experience in a certain situation at a certain time (Tulving, 1993).

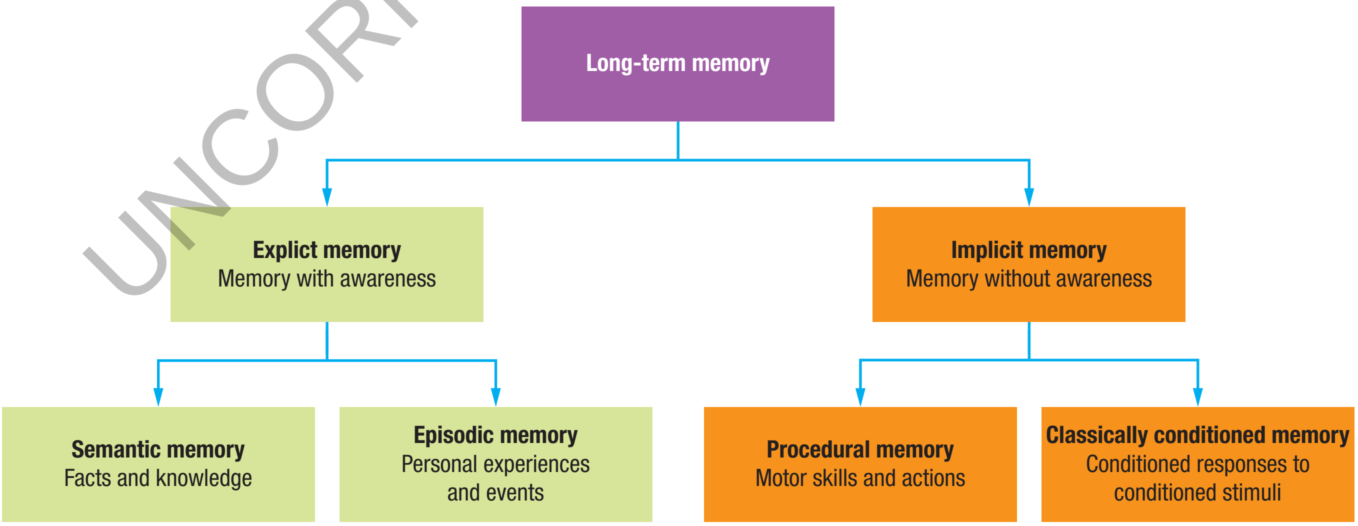

FIGURE 6.19 Long-term memory types and sub-types

Episodic memory is considered to be like a mental 'personal' diary with records of 'autobiographical' episodes we directly or indirectly experience. It is unique as it is the only memory that allows you to travel mentally through time, to remember thoughts and feelings from the recent or distant past. This ability allows you to connect your past and your present and construct a cohesive story of your life. Your memory of your first day at school, where you went for a holiday during the last Christmas vacation, how you felt during a dental visit a week ago, and what you ate for breakfast this morning and how the food tasted, are all examples of episodic memories.

Semantic memory

Semantic memory is the memory of facts and knowledge about the world. It includes our specialised knowledge of:

- facts and knowledge of the kind learned in school — e.g., that humans are mammals and a pie graph is circular
- everyday facts and general knowledge — e.g., that hair can be dyed blonde or that the 2016 summer Olympic Games were held in Rio
- the meaning of words — e.g., that 'assist' means to help
- rules — e.g., the spelling rule 'i before e except after c', or the formula for calculating a mean score
- areas of expertise — e.g., that in a game of chess, a king can be moved only one space in any direction.

Unlike episodic memories, semantic memories are not 'tagged' with details of time and place. For example, you can access a fact such as 'Mick Jagger is the lead singer of the Rolling Stones' that you know you have learnt at some time in the past and not have any idea of when and where you first learned this piece of information.

Some psychologists believe that the distinction between semantic and episodic memories is not as clear-cut as others suggest. They point to memories that seem to be neither purely episodic nor purely semantic but fall into an area in between. For example, consider your memory for a homework task you worked on last night. You probably added knowledge to your semantic memory, which was the likely reason you were asked to do the work. However, you probably also remember details about where you were studying, as well as what time you started and about when you stopped. You may also remember some minor incidents, such as some shouting from a nearby room that upset you or having difficulty finding a reference, all of which are episodic in nature.

FIGURE 6.20 Episodic memory involves memories of personally experienced events that we consciously retrieve and can express to others. For example, these veterans are recalling and describing their war experiences.

Canadian psychologist Endel Tulving (1993), who first described episodic memory, argues that the semantic and episodic memories are sub-systems that store different kinds of information but often work together when we form new memories. In such instances, the memory that is ultimately encoded may consist of an autobiographical episode *and* semantic information. The two might be related, like a container and its contents. For example, your episodic memory of having studied last night also contains semantic knowledge about what you learned.

Other psychologists have proposed that semantic memories may simply be greatly overlearned episodic memories that do not require the ‘time stamping’ that occurs with episodic memories. For example, when did you first learn the meaning of the word ‘tomato’? You probably don’t remember because the information is so well-known to you and when it was learnt matters so little that you can’t remember when you actually first learned it (Thompson, 2000).

FIGURE 6.21 Semantic memory involves memories of facts and knowledge that we consciously retrieve and can express to others. For example, (a) this tour guide is relying on their semantic memory, as is (b) the person recalling a PIN to withdraw money from their account.

LEARNING ACTIVITY 6.9

Reflection

Imagine what life would be like without the ability to form new explicit memories. What are some aspects of your life that would change? For example, what would be the implications on learning at school? playing sport? following the plot of a movie? navigating your way around town? Can you think of other ways this would affect your life?

Implicit memory

Implicit memory involves memory that does not require conscious or intentional retrieval. You are not aware you are remembering, nor are you necessarily trying to remember or aware of ever having remembered something you know you know, but the remembering usually occurs effortlessly. Consequently, it is commonly described as ‘memory without awareness’. Examples of implicit memory include motor skills like brushing your teeth and riding a skateboard. Implicit memory also includes simple classically conditioned responses, such as fears and taste aversions (Schacter, Gilbert & Wegner, 2009).

The term ‘implicit memory’ is used because the existence of a specific memory can be ‘implied’ by (or inferred from) responses that can be observed. For example, your memory for knowing how to tie your shoe laces or ride a bicycle can be judged by watching you do it rather than by asking you to state how you do it. The psychologists who first described implicit memory considered adopting the term ‘unconscious’ or ‘unaware’ instead of ‘implicit’ but decided these terms could create confusion as they are also used to describe other psychological concepts that do not necessarily involve memory (Schacter, 1987).

Implicit memories are also referred to as *non-declarative memories* because people often find it difficult to state or describe in words (‘declare’) what is being remembered, but the memory can be expressed through behaviour. This does not mean that we cannot describe any implicit memory. Sometimes we can and sometimes we can’t. It depends on the specific type of information involved. For example, not all implicit memories are ‘how to …’ memories. We can remember words, shapes or other objects without having a conscious memory of ever having been exposed to them before or any awareness that they actually may be in our memory. When the right cue is used, however, we can retrieve and state this information (see box 6.5 on priming).

Different sub-types of implicit memory have been identified. Two of the most commonly described are called procedural memory and classically conditioned memory.

FIGURE 6.22 If this patient can recall unfamiliar words presented when unconscious during surgery and is unaware of when the words were learnt, then he would be demonstrating implicit memory.

Procedural memory

Procedural memory is the memory of motor skills and actions that have been learned previously. It involves memories of 'how to do something'. Examples of procedural memories include how to brush your teeth, how to use chop sticks, how to play a G chord on a guitar and how to roller blade, even if you have not done so for a long time. Procedural memories are demonstrated through performance (i.e. behaviour) and include what are sometimes called *skill, motor, body* or *muscle* memories.

Procedural memories typically require little or no intentional or conscious attempt to retrieve. For example, if you have not ridden a bicycle for many years, the skills required to do so will be reactivated and brought into conscious awareness with little or no mental effort. What we remember is automatically translated into actions. All you have to do is 'will' the action and it happens, but it happens because you have an implicit memory of how to make that action happen (Schacter, Gilbert & Wegner, 2009).

Procedural memories are often particularly difficult to put into words. For example, try explaining how you balance on a bicycle without falling off when you ride down the street. Similarly, consider a more complex sequence of actions performed by an experienced hockey player. In the course of a match, the player scores a goal after taking a pass and weaving their way through several opponents while maintaining possession of the ball. If asked about the rapid series of motor activities involved in this play, the player will probably have a difficult time stating how to perform every single movement involved.

FIGURE 6.23 Procedural memory involves implicit memory of motor skills and actions, such as how to blow-dry a client's hair.

LEARNING ACTIVITY 6.10

Reflection

Consider the principles and actions required to ride a bicycle. Comment on whether you could verbally describe to someone who is physically able to ride a bike, but has never seen or ridden one, how to successfully do so. Assuming you could prepare a detailed list of written instructions on how to ride a bike, explain whether the person could, as an alternative, carefully read the instructions then hop on a bike and ride off.

Classically conditioned memory

Conditioned responses to conditioned stimuli acquired through classical conditioning are also considered to be a type of implicit memory, particularly those involving fear or anxiety. For example, if you immediately experience fear or anxiety at the sight of a spider or when you think about having to go to the dentist because of past associations with anxiety or pain, implicit memory is involved, whether or not you have an explicit 'declarable' recollection of a relevant past event.

Consider also a taste aversion that may be acquired involuntarily without conscious awareness through classical conditioning. Suppose, for example, that you developed a taste aversion to yoghurt after tasting or eating it and feeling nauseated. If you feel sick whenever you see or think about yoghurt, this is a type of classically conditioned response. The memory of feeling sick comes into your conscious awareness automatically, without any deliberate effort, because of the past association. This means that the memory is implicit.

There are also simple conditioned reflex responses that involve implicit memory. For example, eye blinking to a puff of air and head turning to the sound of a tone that has been acquired through classical conditioning will occur automatically without conscious awareness in response to a relevant stimulus. This also means that the memory is implicit.

FIGURE 6.25 Cooking a beef casserole can involve explicit and implicit long-term memories. Procedural memory is involved in knowing how to brown the meat. Remembering the recipe involves semantic memory. A memory of the time and place of a previous cooking disaster with beef casserole would involve episodic memory.

FIGURE 6.24 If you immediately experience fear or anxiety when you think about having to go to the dentist because of past associations with anxiety or pain, implicit memory is involved.

BOX 6.5

The implicit memory of priming

Not all implicit memories are ‘how to’ memories or conditioned responses. For example, we can learn and remember words, shapes or other objects without having a conscious memory of prior exposure to them or awareness that they may be in our memory. When the right cues are used, however, we can retrieve this information.

Priming is an improvement or change in the ability to remember something as the result of having prior experience with it. Essentially, prior exposure to a stimulus (the ‘prime’) influences a response to a later stimulus. For example, if you were to see a picture of bicycle handlebars drawn from an unusual angle, you would recognise them as part of a bike faster if you had previously seen a more conventional picture of a bike (the ‘prime’ or ‘priming stimulus’). If you had not, you would find them more difficult to identify. Priming is considered by many psychologists to be a type of implicit memory in the sense that it can occur independently of any conscious or explicit recollection of a previous encounter with a particular stimulus (Schacter, 1992; Stevens, Wig & Schacter, 2008).

Priming has mainly been studied in experiments using word completion tests. For example, participants may be exposed to a list of ten words that are rarely used in everyday conversation, such as assassin and sampan. They may be required to rate how much they like or dislike the words so that they do not focus on committing the words to memory. A week or so later, when given a test of explicit memory, the participants have no idea about whether any of the words were on the list. However, when given a word fragment such as a__s__n and s _ m _ _ n and asked to complete it with the first appropriate word that comes to mind, they are more likely to complete the words assassin and sampan than control group participants. Similarly, participants who are shown an entire word such as ‘bird’ or ‘elephant’ will respond more quickly to later presentations of these words than to words they had not previously seen, even though they do not remember having seen the words ‘bird’ or ‘elephant’ earlier.

This priming effect seems to rely on prior exposure to a stimulus even though the person is unaware of the experience. The effect, although sometimes reduced, has been observed in both people with and without amnesia, using different types of words (e.g. meaningful-non-meaningful; familiar-unfamiliar; short-long) and presentations (e.g. visual-auditory; short-long exposure time) (Schacter, 1987; Schacter & Buckner, 1998).

FIGURE 6.26 Have you noticed how your fears are heightened during and after watching a horror film? Prior experience has primed you to more easily notice and recall related instances.

BOX 6.6

Semantic network theory on organisation of information in LTM

Before reading further, recall the names of the 12 months of the year as quickly as you can. How long did it take you? What was the order of your recall? The answer to these questions is probably ‘about 5 seconds’ and ‘sequential order’ (January, February, March …).

Now, try recalling the months in alphabetical order as quickly as you can. How long did it take you? Did you make any errors? It is likely that the first task was completed more quickly and with fewer errors than the second task.

These activities, as basic as they are, demonstrate that your memory for the months of the year has some organisation to it (Tulving, 1983). One of LTM’s most distinctive features is its organisation of information. The task of retrieving information from LTM is vastly different from that of retrieving information from STM. In STM the search-and-retrieve task involves scanning only 7 ± 2 items to locate the relevant information. However, LTM stores such a vast amount of information that it needs some form of organisation to enable storage that assists the retrieval process.

(continued)

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Semantic network theory emphasises organisation of information in terms of connections ('network') based on meaning ('semantic'). It proposes that information in LTM is organised systematically (with a hierarchical structure) in the form of overlapping networks (or 'grids') of concepts that are interconnected and interrelated by meaningful links. According to the theory, each concept, called a *node*, is linked with a number of other nodes (or concepts) in the network. When we retrieve information, cues activate the nodes and the activation of one node causes other related nodes to be activated also, thereby retrieving related information. The more nodes that are activated, the greater the likelihood that the correct information will be retrieved.

Figure 6.27 shows how a small segment of a possible semantic network for animals might be arranged in LTM. Each concept in the network, such as *bird* or *canary*, is organised into a hierarchy in which one concept is a subcategory of another. For example, note how the concept of *animal* is broken down into *bird* and *fish*. Bird and fish are then broken down further into specific examples of each. At each node, certain characteristics of that concept are stored. For instance, the characteristics associated with fish could include fins, swimming, gills and scales.

In reality, LTM contains countless concepts, each with very many connections and links. For example, the network for animals that includes fish could overlap with the network for proteins, which could also include fish as well as nuts, cheese, meat and so on. This system of storing information in terms of meaning is not only effective for organising stored information but also enables its efficient retrieval. For example, if we locate *canary*, we not only know that canaries can sing and are small, but we also know, by moving upwards in the hierarchy, that they have wings and feathers, fly, breathe, eat, move and have skin. This helps make the information-storage system efficient because it minimises the duplication in storage of information, given that every characteristic of each animal does not need to be stored separately with that animal.

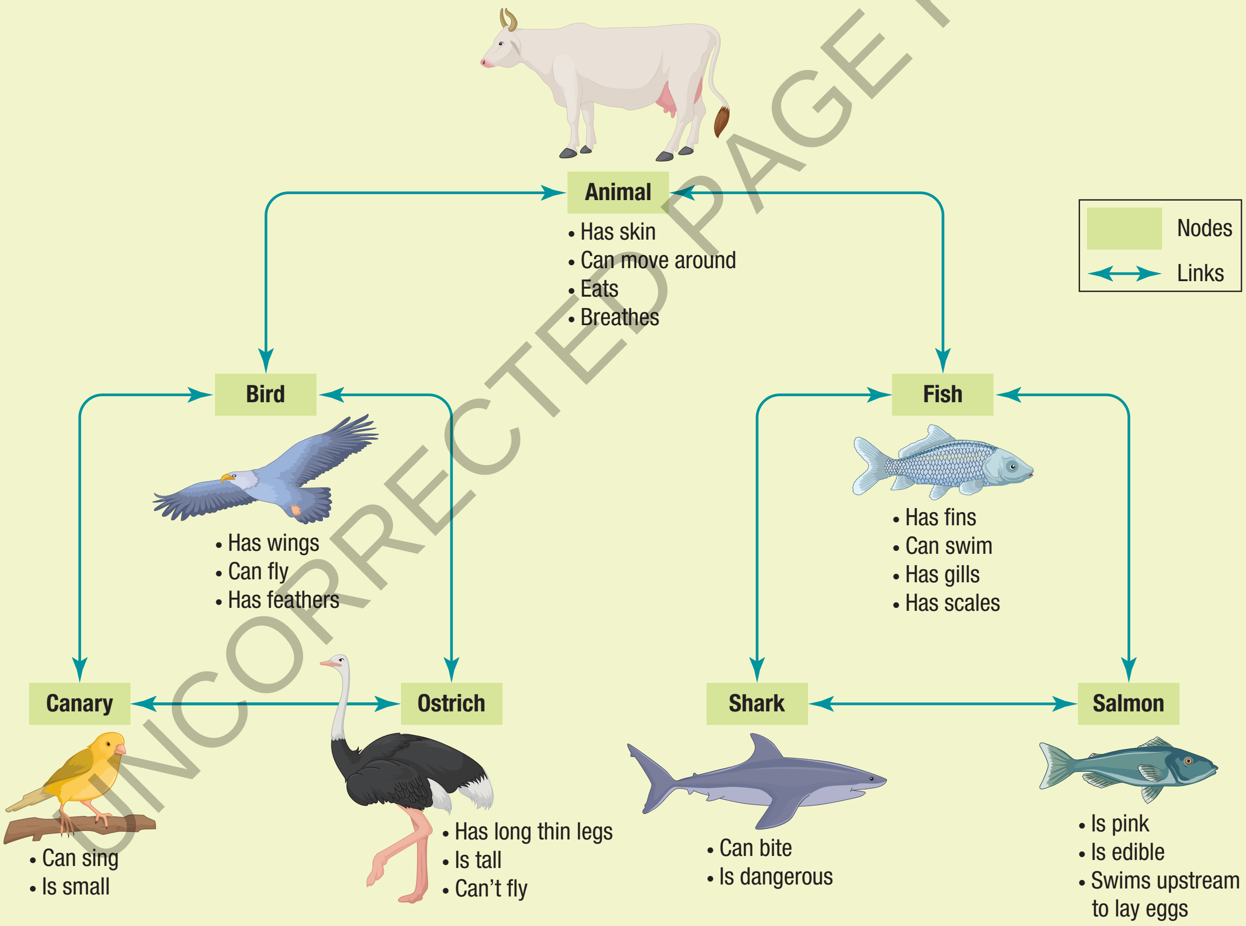

FIGURE 6.27 According to semantic network theory, LTM is organised into semantic networks in which concepts or nodes (such as canary, bird and animal) are interconnected by links. The shorter the link between two concepts, the stronger the association between them. The figure shows only a small segment of a possible network. Other information, such as characteristics of animals, fish, birds and so on, has been left out so that the network is kept simple.

LEARNING ACTIVITY 6.11

Review questions

1 Explain what long-term memory (LTM) is with reference to its function and its storage capacity and duration.

2 (a) LTM is sometimes described as storing ‘inactive’ information. Explain whether this is a suitable description.
   (b) Which other memory store or system could also be described as storing inactive information? Why?

3 (a) Distinguish between implicit and explicit memory with reference to two key features and relevant examples.
   (b) Why are implicit and explicit memory often described as declarative or non-declarative?
   (c) Give examples of when implicit and explicit memory may occur independently of each other.
   (d) Give an example of an implicit memory that does not involve some kind of observable activity.

4 Draw a diagram to show how procedural memory, episodic memory and semantic memory could each be involved in processing information about a competitive tennis match you played in.

5 Make a copy of the LTM chart in figure 6.19 and include information about key features and relevant examples of each subtype of implicit and explicit memory.

LEARNING ACTIVITY 6.12

Identifying LTM types and subtypes

For each of the following activities, name the most likely LTM type/s (explicit or implicit) and the relevant subtype/s. Briefly explain each answer.

(a) describing your first day in Year 7
(b) registering your VTAC PIN
(c) walking on stilts up stairs
(d) recalling the names of Santa’s reindeer
(e) solving a crossword puzzle
(f) texting a phone message
(g) stating a lunch order in a fish-and-chip shop
(h) taking a lunch order in a fish-and-chip shop
(i) describing the plot of a novel
(j) feeling anxious at the sight of a mouse because of a traumatic previous encounter with a mouse
(k) playing hide and seek
(l) a knee jerk reflex CR to a CS
(m) calculating a mean score
(n) giving directions to the principal’s office
(o) writing up a prac. report
(p) recalling a party you attended
(q) recalling the name of your favourite primary school teacher
(r) writing a computer program
(s) playing online Scrabble
(t) becoming extremely anxious when stuck in a lift because of a fear of having been in an enclosed place at some time in the past
(u) playing a car racing video game

BRAIN REGIONS INVOLVED IN THE STORAGE OF LONG-TERM MEMORIES

Our long-term memories are not stored in any one specific brain location. Instead, they are distributed and stored across multiple brain locations. Very simple memories may be formed, encoded and stored at specific locations. The more complex memories, however, typically comprise clusters of information that are stored throughout the brain and linked together by neural pathways. Furthermore, an entire neural pathway can be single memory, a part of multiple memories or include sections of synaptic connections that are involved in one or more other memories (Gazzaniga, Ivry, & Mungun, 2014; Kolb & Whishaw, 2014).

There are, however, some distinguishable brain regions and structures in which different types of explicit and implicit memories are encoded and stored. This does not mean that all areas of the brain are equally involved in memory formation or storage. Different areas may become active as we encode, store and retrieve different types of information.

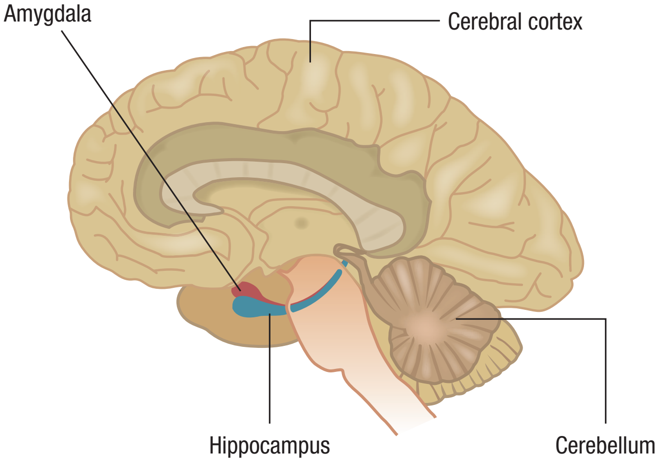

FIGURE 6.28 Some brain regions involved in LTM storage

In this section we focus on the roles of the cerebral cortex, hippocampus, amygdala and cerebellum in the storage of implicit and explicit long-term memories. We also consider interactions between these regions, highlighting the complex yet integrated nature of brain function. In relation to long-term memory encoding, storage and retrieval, this often involves parallel processing and exchange of information within and between different brain regions.

Roles of the cerebral cortex

The cerebral cortex is the thin outer, wrinkly looking layer of neural tissue that covers the largest part of the brain (the cerebrum). Anatomically, it is divided into two hemispheres, each of which has four lobes. Unlike most structures that connect only to a limited number of brain regions, the cortex is connected to virtually all parts of the brain. This allows it to take part in almost everything we consciously think, feel and do. Basically, the cerebral cortex is what makes us who we are as human beings and distinguishes us from other animals.

Generally, long-term explicit semantic and episodic memories are widely distributed throughout the cortex. Their permanent storage tends to be in the areas where the relevant information was first processed. For example, an episodic memory of a rock concert you may attend will have different components, such as the name of the band, visual images of the various band members, the band's sounds and so on. It is therefore likely that the name of the band will be stored in a cortical area involved with language (frontal lobe), images in visual cortex (occipital lobe) and sounds in auditory cortex (temporal lobe). Furthermore, the different components are linked to ensure they do not remain a collection of separate memories.

When required, the separate parts are gathered together and reconstructed as a single, integrated memory for retrieval into our conscious awareness. This can be likened to pieces of a jigsaw coming together to create a vivid recollection. The cortex has a crucial role in this process, particularly for explicit memories (Bergland, 2015).

Through continual use of this network when recalling the concert, the groups of neurons involved in storing the different bits of information will repeatedly fire together, strengthening their connections as they become tied together as a single memory. Of course, some components of the memory may also be involved other memories within the same network or alternative networks.

Given that different cortical lobes are associated with different functions and processing of specific types of information, researchers have investigated whether particular lobes are more likely to store semantic or episodic memories. Although more research remains to be done on this question, neuroimaging studies indicate that semantic memories tend to be stored throughout the cortex, most likely in both of the frontal and temporal lobes. Episodic memories tend to also be stored throughout the cortex, perhaps especially in the right frontal lobe (particularly the prefrontal cortex just behind the forehead) and the right temporal lobe. Studies of brain injured patients also implicate the frontal and temporal lobes as being more significantly involved in explicit memory processes than the other lobes (Breedlove, Watson & Rosenzweig, 2010; Gazzaniga, Ivry & Mungun, 2014).

FIGURE 6.29 A close-up of a human brain's cerebral cortex. The protective membranes (meninges) have been peeled back to reveal the detail of the bumps and grooves.

Roles of the hippocampus

Just above each ear, deep within the brain's medial ('middle') temporal lobe area, on the edge of and just under the surface of the cerebral cortex, is the hippocampus. It is also part of the brain's limbic system involved in emotion and various other functions, together with the amygdala and other structures. The hippocampus is therefore connected to the amygdala and also has numerous connections to adjacent cortex and sub-cortical areas.

As shown in figure 6.30, the hippocampus is tubular and curved, somewhat like the shape of a seahorse (after which it is named). In humans, it is about 3.5 centimetres long and we have two of them — one in each hemisphere.

The hippocampus is the part of the brain that turns short-term memories into long-term memories. It is crucial in the consolidation of new semantic and episodic memories so that they are neurologically stable and long-lasting, but is not directly involved in the formation of implicit procedural or classically conditioned memories. For example, you could have your hippocampus surgically removed and probably still encode and store memories for motor skills and classically conditioned responses (Milner & Corkin, 2010; Ogden & Corkin, 1991; Thompson, 2000).

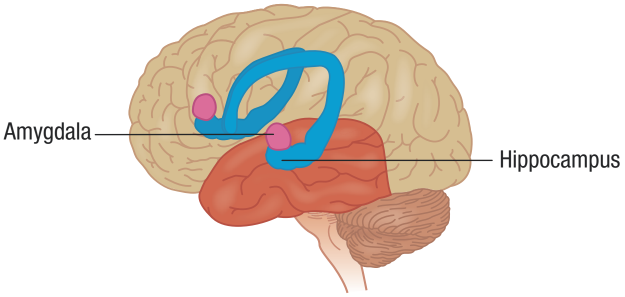

FIGURE 6.30 Locations of the hippocampus and amygdala

Although the hippocampus is a vital processing site for explicit memories, it is believed that it does not permanently store any memories itself. Instead, it transfers them to the cerebral cortex for long-term storage. The storage most likely occurs in the areas that initially processed the information. Links need to be established between different components of a memory to enable retrieval as a single memory. It is believed that the hippocampus plays a significant role in achieving this through interaction with the cortex and other medial temporal lobe areas before the memory is gradually transferred.

Precisely when hippocampal involvement is no longer required after a memory is moved to the cerebral cortex remains unclear. Studies of people and animals with brain damage and experiments using neuroimaging techniques with non-brain damaged participants suggest that it probably has a role in the retrieval of explicit memories as well.

Through its interaction with the amygdala, the hippocampus also plays a role in the formation of emotional memories, particularly the explicit memory component of an emotional event. When emotionally aroused, we form semantic and episodic memories about the situations in which these occur and the hippocampus enables neural representations of this information as explicit memories. For example, when you have an emotionally traumatic experience, your amygdala and hippocampus encode different aspects of the emotionally arousing event for storage in your long-term memory. When you retrieve the memory from the cerebral cortex at some time in the future, the activity of the hippocampus during memory formation will enable you to remember such aspects as where the event happened, when it happened, and whom you were with at the time when you retrieve the memory. These details are explicit memories. Meanwhile, as your amygdala is activated during the retrieval process, you will also remember the emotional arousal content, and sympathetic nervous system reactions that have been linked to the memory may be initiated; for example, your muscles may tighten, your heart may beat faster, your stomach may feel as if it is tied up in knots, and so on. This component is implicit memory.

The hippocampus is also important for *spatial memory*, which is an explicit memory for the physical location of objects in space. Spatial memory is what enables us to navigate from place to place and to learn and remember locations. It is sometimes described as our brain's inner global positioning system — its GPS.

The role of the hippocampus in spatial memory was first identified through research with rats. American psychologist John O'Keefe and his student Jonathan Dostrovsky (1971) found that certain neurons in the right hippocampus of a rat's brain are extremely active when a rat is in a specific place in the environment. These neurons, called *place cells*, become relatively inactive until the rat passes through that location again. It is thought that the hippocampal place cells encode spatial location information and create a kind of 'mental map' in the brain to help recognise locations. In 2003 place cells were discovered in the human hippocampus by other researchers and in 2014 O'Keefe was awarded the Nobel prize in physiology or medicine for his research findings with rats (Sanders, 2014).

FIGURE 6.31 The hippocampus is crucial in the consolidation of new semantic and episodic memories so that they are neurologically stable and long-lasting. This helps ensure pleasant holiday memories are stored relatively permanently.

Because the hippocampus has so many connections to other parts of the brain, it remains unclear as to whether some part of a spatial memory is actually stored in there. There is research evidence, however, that the hippocampus is involved to some extent in the retrieval of spatial memories. For example, neuroimaging studies with people show activation of the right hippocampus in particular when navigating in familiar locations and retrieving directions (see box 6.7).

BOX 6.7

The hippocampus of London taxi drivers

Studies of London taxi drivers have demonstrated the role of the right hippocampus in spatial learning and memory by people within large, natural environments. For example, to become a taxi driver in London, individuals have to go through a comprehensive training course for about two years and then pass a strict test of their ability to find the shortest route between any two locations. As a result of this type of training and assessment, London taxi drivers have become renowned for their ability to efficiently navigate their way throughout one of the most complex and largest metropolitan areas in the world without using a street directory (or GPS).

When MRI scans of London taxi drivers (who find new routes daily) are compared with a control group who do not drive taxis, they show that the rear part of the right hippocampus of taxi drivers is significantly larger. Studies have also found a significant relationship (positive correlation) between years of taxi-driving experience and growth of the hippocampus — the more years an individual has driven a taxi, the larger the hippocampal area, and vice versa (Maguire, et al., 2000).

FIGURE 6.32 London taxi drivers are renowned for their spatial navigational skills and have been found to have a larger right hippocampus.

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Psychology Today article: How big is your hippocampus? Does it matter? Yes and no

LEARNING ACTIVITY 6.13

Visual presentation

Make a copy of figure 6.30 showing the location of the hippocampus. In point form within the diagram, list the roles of the hippocampus in memory.

Roles of the amygdala

The amygdala (pronounced *uh-MIG-duh-luh*) is a small structure (about 1.5 cm long) located just above and interconnected with the hippocampus in the medial temporal lobe. Like most other brain structures, we have an amygdala in each hemisphere. The amygdala is also connected with many other brain regions and structures, thereby allowing it to participate in a wide variety of neurological activities.

The amygdala is best known for its role in processing and regulating emotional reactions, particularly strong, ‘negative’ emotions such as fear and anger (including aggression). For example, your amygdala enables you to detect possible danger when approached by a snarling dog and to recognise fear in other people from their facial expressions before they even say a word. There is considerable research evidence that both people and animals without an amygdala cannot learn to fear things that signal danger, to express fear in appropriate situations and also lose learned fears. For example, monkeys normally feel threatened by and are afraid of snakes. But if its amygdala is damaged, a monkey loses its fear of snakes and other natural predators (Davis & Whalen, 2001; Thompson 2000).

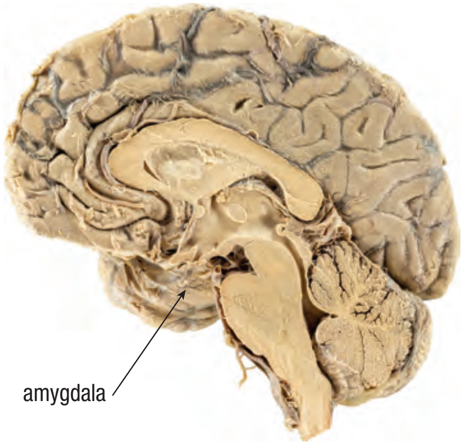


FIGURE 6.33 Location of the amygdala

The amygdala is also involved in the formation of a wide range of other emotional memories, both positive and negative. A considerable amount of the research on its role has been on classically conditioned fear responses involving implicit memory.

In a typical experiment, rats are exposed to a specific stimulus such as blue light that is neutral — the light is ‘meaningless’ and does not produce any reaction by the rat. The light is then followed by an electric shock, which produces a fear response. Eventually, through pairing of the light and shock so that they occur at about the same time, the previously neutral light produces the fear response on its own. If one particular part of the amygdala is then damaged or removed, this interferes with the acquisition and expression of the conditioned fear response to the light alone learned during the experiment (LeDoux, 2000). Similarly, people with damage to their amygdala are typically unable to acquire a conditioned fear response. These individuals are likely to form conscious explicit memories involving the details of the experience, but not an implicit memory that would enable them to produce or express the fear response.

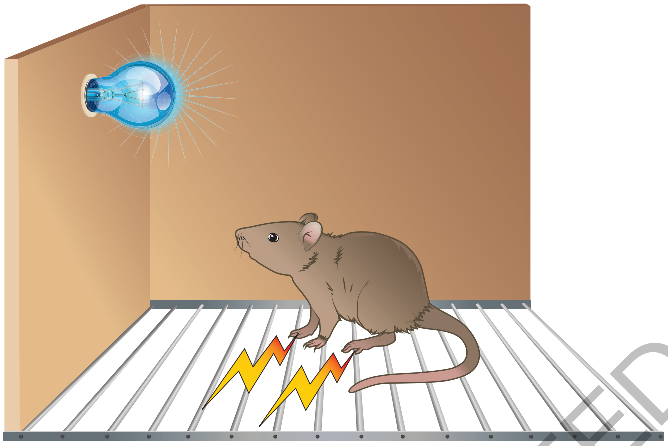


FIGURE 6.34 Conditioning a fear response to previously neutral light

Classically conditioned emotional responses involve implicit memory because they occur involuntarily in the presence of a relevant environmental stimulus. There is no intentional conscious recall and the memory can be observed through the specific reactions associated with the conditioned response. We just ‘react’ immediately and consciously evaluate whether there is any actual danger afterwards.

As you are aware, we are more likely to remember events that produce strong emotional reactions than events that do not. It appears that the level of emotional arousal at the time of encoding influences the strength of the long-term memory formed of that event. This is believed to be partly attributable to the increased amount of the noradrenaline in the amygdala during times of heightened emotional arousal. When released at such times, adrenaline induces the release of noradrenaline in the amygdala. The presence of noradrenaline is believed to stimulate the amygdala to attach emotional significance to the experience and signal the hippocampus to encode and ensure long-term storage of the relevant emotional details during the memory consolidation process. Consequently, the amygdala also contributes to the formation and storage of explicit memories (see figure 6.35). This is apparent in a specific type of episodic memory known as a flashbulb memory.

A *flashbulb memory* is a vivid and highly detailed memory of the circumstances in which someone first learns of a very surprising, significant or emotionally arousing event; for example, when hearing about the unexpected death of an important person in their life or of a shocking incident that dominates the news. Many years later people can remember details about where they were, what they were doing, who they were with and what their emotional reaction was to the event (Hamann, 2009; Phelps, 2004; Richter-Levin, 2004).

Although the amygdala has a vital role in the formation of emotional memories and the expression of their emotional qualities it is believed that it does not permanently store emotional memories. This includes emotional memories that do not involve fear, such as positive memories associated with reward (Gazzaniga, Ivry, Mangun, 2014; McGaugh, 2013; Paré, 2003; Thompson, 2000).

FIGURE 6.35 Flashbulb memories are so named because of the photographic nature of the memory of the event. Many people report flashbulb memories for the emotionally charged event of the September 11, 2001, terrorist attack on the World Trade Center in New York.

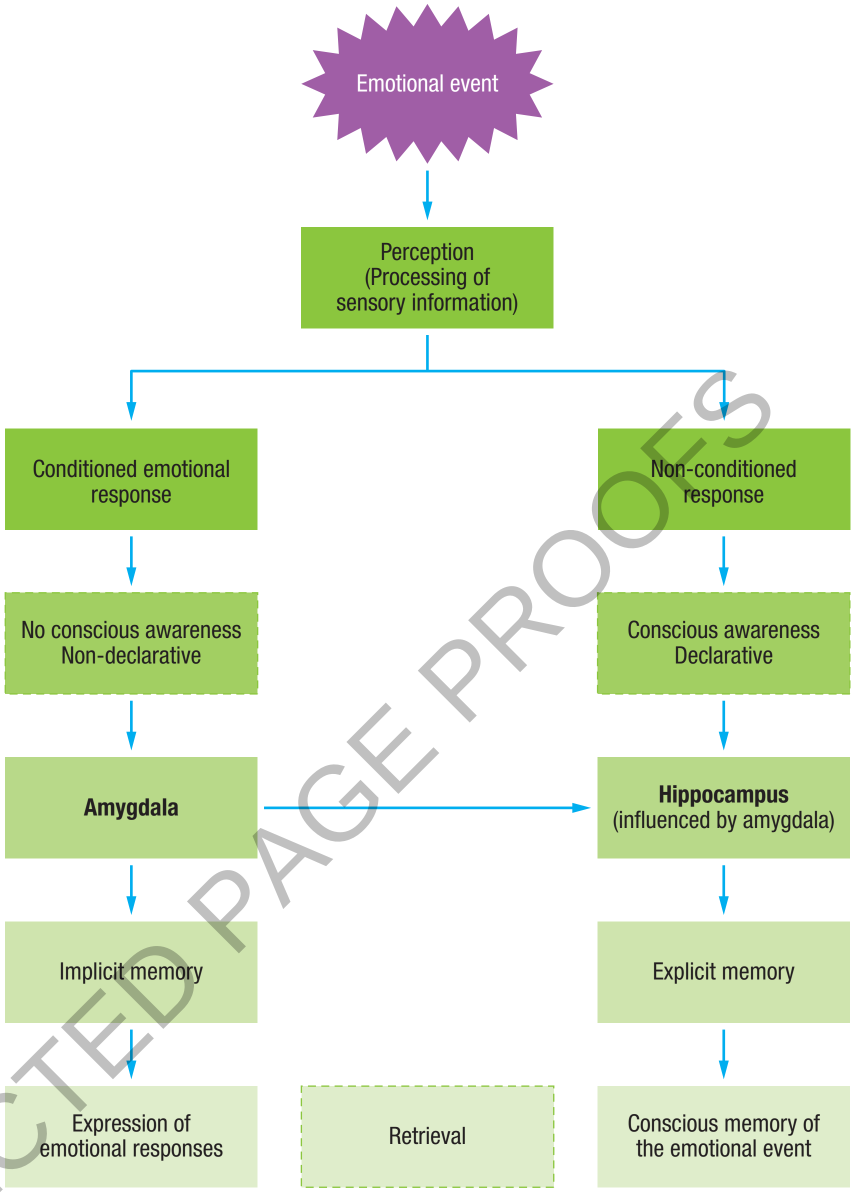


FIGURE 6.36 The amygdala is crucial to the formation of implicit memories involving classically conditioned fear responses, and can also contribute to explicit memories by influencing the activity of the hippocampus.

Roles of the cerebellum

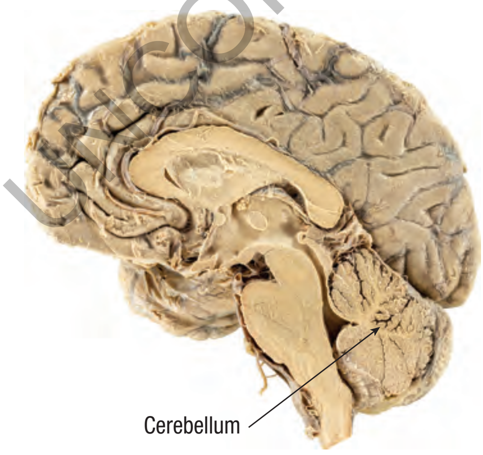


FIGURE 6.37

Located at the base of the brain and at the rear, the cauliflower-shaped cerebellum that looks like a mini brain contains more neurons than the rest of the brain combined, even though it accounts for only 10% of the brain's total volume. Long-term depression (LTD) was originally discovered in the cortex of the cerebellum, then later found to also occur in the hippocampus and elsewhere in the CNS.

The cerebellum, like many other brain structures, has multiple roles. For example, it coordinates fine muscle movements, regulates posture and balance, and contributes to various perceptual and cognitive processes. It is probably best known for its involvement in activities requiring a skilled sequence of movements that require timing and are made with speed, ease and fluency, such as when touch-typing or playing the piano. However, it also plays important roles in everyday voluntary, purposeful movements, such as when reaching to pick up a cup of coffee, so that your arm and hand make one continuous movement. Consequently, damage to the cerebellum makes it difficult to time and coordinate muscle control for everyday activities like talking, reaching, walking, brushing teeth or throwing a ball.

There is considerable research evidence that the cerebellum is directly involved in the encoding and temporary storage of implicit procedural memories for these and numerous other motor skills. It is crucial for motor learning and the execution of voluntary movements, but not their long-term storage as well-learned motor responses are believed to be stored in the cerebral cortex like many other types of memories. However, the cerebellum does form and store implicit memories of simple reflexes acquired through classical conditioning, such as associating a sound with an impending puff of air and consequently blinking in anticipation of the puff.

Although the cerebellum plays a key role in motor learning and is the permanent storage site for a range of conditioned reflexes, other brain regions and structures such as the basal ganglia and motor areas of the cerebral cortex also play crucial roles in the learning and memory of simple and complex motor skills. In addition, as shown in figure 6.38, the cerebellum contributes to spatial learning, navigation and memory, primarily through its role in visual sensori-motor coordination (Colombel, Lalonde & Caston, 2003; Rochefort, Lefort & Rondi-Reig, 2013).

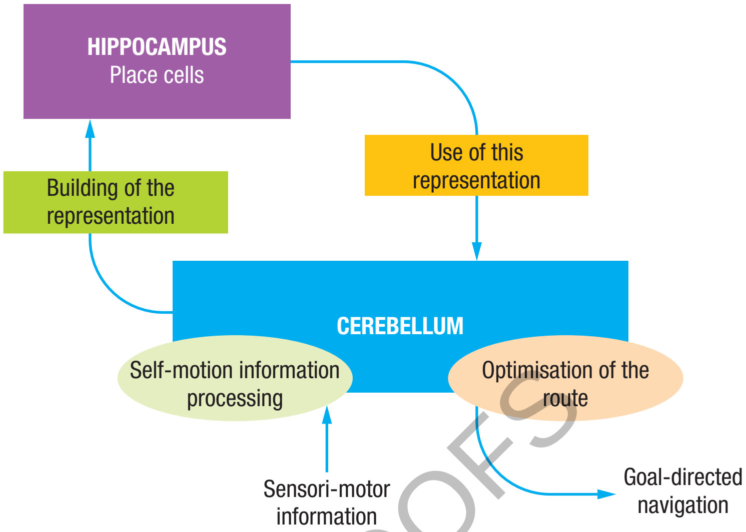


FIGURE 6.38 The cerebellum may contribute to spatial navigation at two levels, first in processing self-motion information to build spatial representation in the hippocampus at the level of place cells, and second in using this spatial representation to perform an optimal route toward a goal.

Source: Rochefort, C., *Lefort,J.M.*, & Rondi-Reig, L. (2013). The cerebellum: A new key structure in the navigation system. *Frontiers in Neural Circuits*, 7(35), 1–2.

LEARNING ACTIVITY 6.14

Summary of brain region roles in memory storage

Part A

Complete the following table to summarise the roles of different brain regions in the storage of implicit and explicit memories.

		Explicit memory		Implicit memory	
Brain region	**Location of the region**	**semantic**	**episodic**	**procedural**	**classical conditioning**
cerebral cortex					
hippocampus					
amygdala					
cerebellum					

Part B

Make a copy of the brain on the right and use it to further summarise the information in the table above.

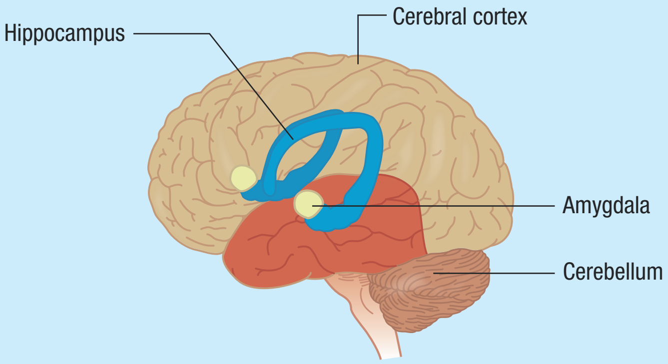
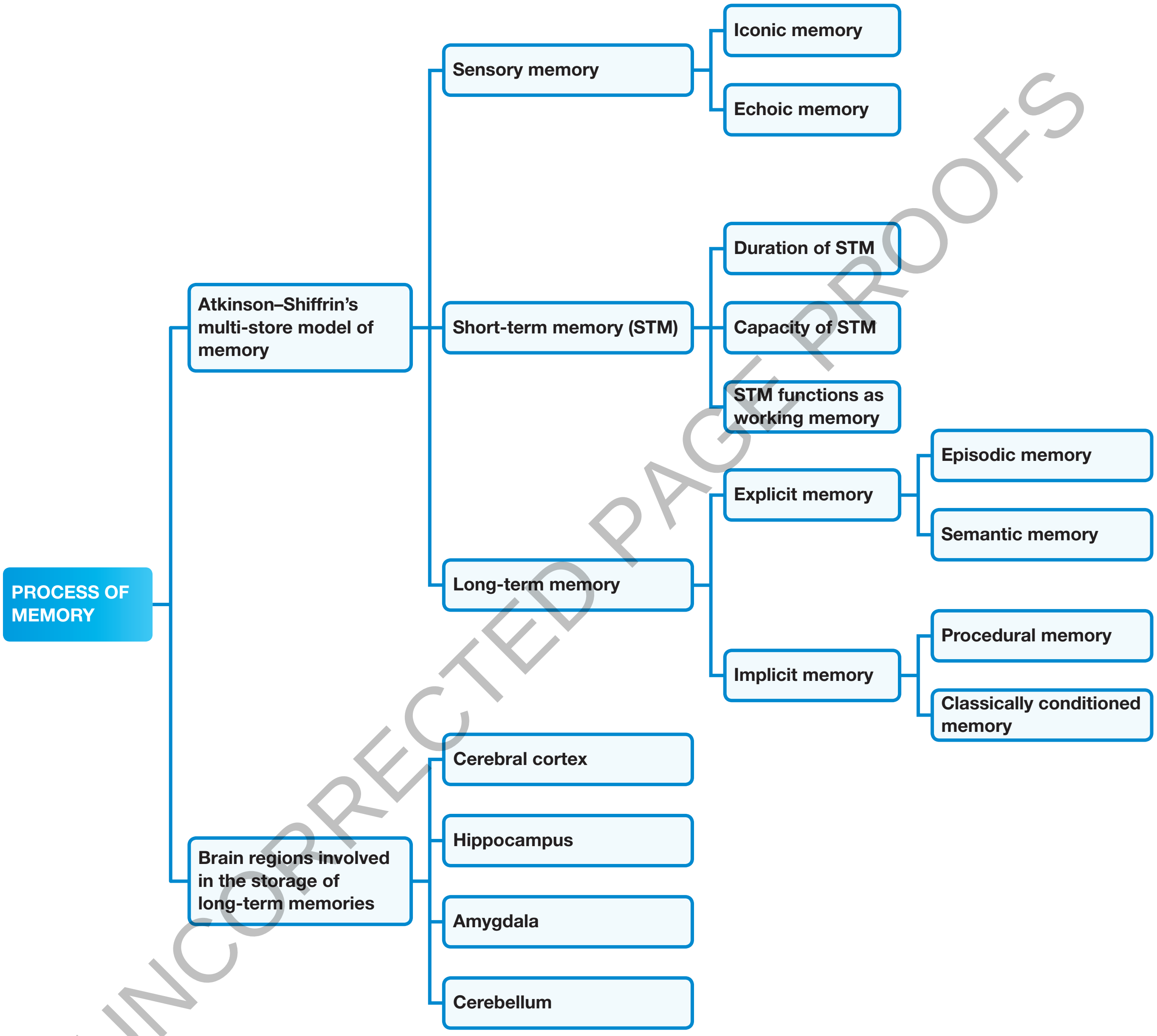


FIGURE 6.39

CHAPTER 6 REVIEW

CHAPTER SUMMARY



KEY TERMS

Atkinson–Shiffrin multi-store model p. 00
control processes p. 00
echoic memory p. 00
episodic memory p. 00
explicit memory p. 00
iconic memory p. 00
implicit memory p. 00
long-term memory (LTM) p. 00
memory p. 00
procedural memory p. 00
semantic memory p. 00
sensory memory p. 00
short-term memory (STM) p. 00
structural features p. 00

LEARNING CHECKLIST

Complete the self-assessment checklist below, using ticks and crosses to indicate your understanding of this chapter's key knowledge (a) before and (b) after you attempt the chapter test. Use the 'Comments' column to add notes about your understanding.

Key knowledge I need to know about	Self-assessment of key knowledge I understand *before* chapter test	Self-assessment of key knowledge I need to revisit *after* chapter test	Comments

CHAPTER TEST

SECTION A — Multiple-choice questions

Choose the response that is **correct** or that **best answers** the question.

A correct answer scores 1, an incorrect answer scores 0.

Marks will **not** be deducted for incorrect answers.

No marks will be given if more than one answer is completed for any question.

Question 1

Memory is best described as

A. a unitary system through which information flows back and forth.
B. the storage and recovery of information acquired through learning.
C. a multi-store system in which all information is continually processed.
D. three independent systems called sensory memory, short-term memory and long-term memory.

Question 2

Which type of long-term memory is likely to be involved when a person recalls how to switch on an iPad after not having used one for some time?

A. working
B. semantic
C. episodic
D. procedural

Question 3

The best way of prolonging the storage duration of information well beyond its normal limit in short-term memory is through

A. encoding.
B. rehearsal.
C. recall.
D. attention.

Question 4

You switch off a bedside alarm clock but can still hear it ringing for a couple of seconds. This is most likely due to ______ memory.

A. episodic
B. working
C. iconic
D. echoic

Question 5

Which of the following activities involves implicit memory?

A. distinguishing between a shark and a dolphin
B. telling a friend about how the weekend was spent
C. swimming in water using the freestyle stroke
D. recalling a word for a crossword puzzle

Question 6

Which of the following long-term memories is most likely stored in the cerebellum?

A. an episodic memory of a celebration
B. any type of sensory memory
C. a classically conditioned fear response
D. a classically conditioned patellar (knee jerk) reflex

Question 7

What is required for information to be transferred from a sensory register to short-term memory?

A. attention
B. encoding
C. rehearsal
D. retrieval

Question 8

Which sub-type of long-term memory is likely to be involved when someone recalls their first day as a VCE student?

A. procedural
B. episodic
C. semantic
D. classically conditioned

Question 9

Which of the following statements about the hippocampus is correct?

A. The hippocampus is the permanent storage site for explicit memories.
B. The hippocampus is the permanent storage site for classically conditioned memories.
C. Procedural memories do not appear to involve the hippocampus at all.
D. The medial temporal lobe is located in the hippocampus.

Question 10

Which memory system or sub-system stores information for the shortest duration?

A. short-term memory
B. sensory memory
C. iconic memory
D. echoic memory

Question 11

In which brain region is it most likely that the long-term memory of a visual image of an artwork is stored?

A. hippocampus
B. amygdala
C. visual cortex
D. frontal lobe

Question 12

Your ability to use language efficiently in everyday conversation is an example of

A. implicit memory.
B. explicit memory.
C. conditioning
D. classical conditioning.

Question 13

Which of the following shows the most likely correct order of memory processes?

A. attention -> LTP -> encoding -> storage -> retrieval -> perception of stimuli
B. perception of stimuli -> encoding -> LTP -> storage -> retrieval
C. attention -> perception of stimuli -> LTP -> encoding -> storage -> retrieval
D. perception of stimuli -> encoding -> storage -> LTP -> retrieval

Question 14

Most of the information that reaches sensory memory is

A. lost from the relevant sensory register.
B. immediately transferred to short-term memory.
C. encoded before transfer to short-term memory.
D. processed in some way before transfer to short-term memory.

Question 15

Sara is a proficient keyboarder. For example, when creating a Word document, she can key in a complex sentence with eyes closed, very quickly and accurately. However, when asked to name the location of the seven letters on the bottom row of a keyboard, from left to right, in their correct order, she cannot do so.

Sara's keyboarding with eyes closed relies on ______ memory, whereas correctly naming the letters relies on ______ memory.

A. implicit procedural; explicit semantic
B. explicit procedural; implicit semantic
C. implicit procedural; explicit episodic
D. implicit classically conditioned; explicit semantic

SECTION B — Short-answer questions

Answer **all** questions in the spaces provided. Write using blue or black pen.

Question 1 (1 mark)

When we first experience an event, all the distinct aspects are stored in different regions of the brain, yet we are still able to remember them all later on. The brain structure called the ______________________________ is critical to this process, associating all these different aspects so that the entire event can be retrieved as unified memory.

Question 2 (2 marks)

Long-term semantic and episodic memories are formed in the ____________________________ and stored in the ______ ____________________________.

Question 3 (2 marks)

(a) What is the main function of long-term memory? 1 mark

(b) We become consciously aware of information stored in long-term memory by retrieving it to ____________________ ____________________. 1 mark

Question 4 (3 marks)

List three different types of classically conditioned memories.

Question 5 (2 marks)

Explain why short-term memory may be described as 'working memory'.

Question 6 (2 marks)

You start a new job as a casual cook in a fast-food outlet where orders are called out for you to prepare.

(a) How many different items are you likely to remember in one order. 1 mark

(b) Explain your answer. 1 mark

Question 7 (2 marks)

Explain the difference between encoding and retrieval in relation to long-term memory.

Question 8 (4 marks)

Distinguish between implicit and explicit memory with reference to an example and sub-type of each memory.

Question 9 (4 marks)

Distinguish between structural features and control processes of the Atkinson–Shiffrin multi-store model with reference to an example of each of these properties.

Question 10 (4 marks)

(a) Where in the brain is the amygdala located? (1 mark)

(b) Describe the interaction between the amygdala and hippocampus in long-term memory formation and storage. (3 marks)

Return to the checklist on page XXX and complete your self-assessment of areas of key knowledge where you need to do more work to improve your understanding.

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The answers to the multiple-choice questions are in the answer section at the end of this book and in eBookPLUS.

The answers to the short-answer questions are in eBookPLUS.

Note that you can also complete Section A of the chapter test online through eBookPLUS and get automatic feedback. **int-0000**