1 Concepts of Memory

The chapter opens by defining learning and memory. Their neurophysiological basis is explained. A strong emphasis is placed on the role played by modification of the synapse, the point of communication between neurons. It is shown how this process of modification underpins neural plasticity and may facilitate learning and memory.

There is a brief overview of the history of memory theory. It is shown, in particular, that the work of some early theorists in this field, such as James and Bartlett, fits well with some occupational therapy concepts. There is also a discussion of the 'cognitive revolution' that took place in psychology in the United States in the 1950s. Some practical applications of the 'information processing' turn that this involved are explained.

The chapter also contains a detailed description of the case of Henry Molaison. This is justified by the far-reaching implications of these findings for learning and memory theory. Following from this, space is devoted to a detailed discussion of the 'hippocampal memory system'.

Some leading theorists have developed models of memory. The chapter includes a detailed discussion of Tulving's hierarchal model of procedural, semantic and episodic memory. In addition, there is consideration of the 'multicomponent working memory' model, which is particularly associated with the work of Baddeley. Also, there is discussion of the concept of prospective memory and reflection on the work of Luria and Vygotsky on the socio-historical origins of cognitive processes.

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Defining Learning and Memory

The learning process allows the acquisition of novel information (Gazzaniga et al. 1998, 2009). Memory is the persistence of this learned content in a condition in which it can be retrieved in the future (Gazzaniga et al. 1998, 2009; Schacter and Wagner 2013). This linkage means that scientific accounts have often discussed learning and memory in combination (Tulving and Madigan 1970; Gazzaniga et al. 2009).

Memory's role in occupation has been explored by occupational therapy theorists including Hagedorn (2000, p. 31), who defined it as a 'skill component' of performance, and Radomski (2002, p. 198), for whom it was a 'primary

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cognitive capacity' underpinning 'higher level thinking abilities'. Kielhofner (2008, p. 18), meanwhile, described memory as an aspect of cognition that could support 'performance capacity'. For all these authors memory, then, is fundamental to effective occupational performance.

For Kandel et al. (2000), learning and memory are the supreme processes through which the environment influences our behaviour. So, learning and memory formation imply a *change* in the organism at some level and this requires both stable body structures and the capacity to modify these in response to experience (Kielhofner 1995; Rose 1992). The persistent stability of the organism is called 'specificity'; the ability to change, 'plasticity' (Rose 1992, p. 137).

These themes of change and stability have also been discussed by occupational therapy theorists. Kielhofner (1995, p. 10), for example, drew on 'general, dynamical and open systems theories' in his examination of human occupation. A system is made up of components that function in concert for a specified purpose: an 'open system' constantly changes and organises itself as it interacts with its environment, while 'dynamical systems' describe the process by which a novel order emerges following an epoch of flux (Kielhofner 1995, p. 9). In the following section, these themes are explored in relation to learning and memory from within a 'physiological frame of reference' (Hagedorn 1992).

Neurophysiological Mechanisms of Learning and Memory

In order to understand the 'organic substrate' (Trombly 2002, p. 7) that allows the changes brought about through learning to take place while maintaining the continuity of the organism, it is first important to grasp that communication within the nervous system requires the transfer of information between neurons (Bear et al. 2016). Neurons are nerve cells that possess electrical excitability and underpin functions such as learning and memory (Tortora and Derrickson 2011). Communication between neurons occurs at sites called synapses, where a presynaptic neuron signals to a postsynaptic neuron; typically, the 'presynaptic element' is the terminal ending of an axon, while the postsynaptic component is a dendrite on the postsynaptic neuron (Bear et al. 2016). This communication is discussed in more detail later in the chapter.

In most synapses, the presynaptic and postsynaptic neuronal membranes are separated by a microscopic gap, the synaptic cleft (Bear et al. 2016). The presynaptic axon terminal houses 100–200 microscopic spheres named 'synaptic vesicles' that contain chemicals called neurotransmitters, the medium of communication between the neurons (Bear et al. 2016; Siegelbaum and Kandel 2013). Vesicles release their neurotransmitter into the synaptic cleft in response to an electrical signal called an action potential, or nerve impulse, travelling to the axon terminal of the presynaptic neuron (Bear et al. 2016; Siegelbaum and Kandel 2013; Tortora and Derrickson 2011). The neurotransmitters bind to receptor sites on the postsynaptic neuron; these sites are normally closed, but they open when particular neurotransmitters cleave to them

(Bear et al. 2016). The synaptic cleft, then, is the region of communication between the pre- and postsynaptic neurons.

The receptor sites are located on channels in the postsynaptic cell membrane. When neurotransmitters bind to these sites, the channels open. The channels are specialised to permit only certain ions to enter or exit the cell (Bear et al. 2016; Tortora and Derrickson 2011). Ions are atoms or molecules with an electrical charge, conventionally labelled as either 'positive' or 'negative', meaning that they can cause a force of attraction or repulsion when close to another ion. The movement of these ions creates a current across the cell membrane, with implications that are explained later.

The ions that cross the postsynaptic membrane enter from the extracellular fluid and cause changes in the *voltage* of the membrane of the postsynaptic neuron (Bear et al. 2016; Tortora and Derrickson 2011). Voltage is a measure of the difference in electrical energy between two locations, in this case between the outer membrane and inner membrane of the neuron. The difference is created as a result of the varying amounts of negatively and positively charged ions on either side of the membrane. This difference results in a *membrane potential*, typically of −70 mV, a value indicating that the inner membrane of the neuron is negatively charged when compared with the outer membrane (Gazzaniga et al. 2009). As already stated, the neuron is electrically excitable, meaning that the membrane potential can change as a result of a stimulus, so this value is named the *resting* membrane potential (Martini 2018). The resting membrane potential, then, can change as result of ions entering the neuron.

Sodium ions have a positive charge, so if sodium ion channels open and these ions enter the postsynaptic cell, they cause an increase of positive charge in the region around the cell's inner membrane (Tortora and Derrickson 2011). This leads to a reduction in the negativity of the membrane potential, a phenomenon labelled *depolarization* (Siegelbaum and Kandel 2013; Bear et al. 2016). If potassium ion channels open, leading to an outflow of these positively charged ions, this leads to a rise in negative charge at the inner cell membrane, resulting in an increase in the negativity of the membrane potential, a phenomenon labelled *hyperpolarisation* (Tortora and Derrickson 2011). The opening of chloride channels will lead to an inflow of these negatively charged ions, also leading to hyperpolarisation (Tortora and Derrickson 2011).

These variations in the membrane potential make it more or less likely that an action potential, also called a nerve impulse, will be generated. The action potential is an electrical signal that conducts along the axon of the neuron without losing strength, a process called propagation (Tortora and Derrickson 2011). As already shown, once the action potential reaches the axon terminal it causes neurotransmitter to be released into the synaptic cleft, so that interneuronal communication can occur. If hyperpolarisation occurs in the postsynaptic neuron, this results in an *inhibitory postsynaptic potential,* meaning that an action potential will not be generated (Siegelbaum and Kandel 2013; Bear et al. 2016). However, when *depolarisation* occurs in the postsynaptic neuron, there will be an *excitatory postsynaptic potential* (Siegelbaum and Kandel 2013; Bear et al. 2016). If the excitatory postsynaptic potential results in a change in the membrane potential to a threshold value of −55 mV, then an action potential will be generated (Tortora and Derrickson 2011).

Long-Term Potentiation

Since the nineteenth century, researchers have suggested that the process of learning and formation of memories is underpinned by modification of the synapse (Rose 1992; DeFelipe 2006). This concept was given a clear formulation by Hebb (1949), who proposed that, if a presynaptic neuron repeatedly partook in activating a postsynaptic cell, then its ability to activate that cell would increase; he commented that 'this changed facilitation . . . constitutes learning' (Hebb 1949, p. 65). Hebb's (1949) postulate, therefore, was that learning involved the strengthening of the connection between synapses, and this required simultaneous activity at the pre- and postsynaptic neurons (Lamprecht and LeDoux 2004).

Neurophysiological evidence that provided support for Hebb's postulate was first described in detail by Bliss and Lømo (1973; Bliss and Collingridge 1993). These researchers had noticed that electrical stimulation in one part of the rabbit hippocampus (a brain region that is known to be involved in learning and memory and that will be discussed further later in the chapter) led to an increase in electrical activity in neurons in another hippocampal region that had not been directly stimulated (Bliss and Lømo 1973). The depolarisation of these latter cells lasted for up to 10 hours, a phenomenon they labelled 'long lasting potentiation' (Bliss and Lømo 1973, p. 339).

The phenomenon described by Bliss and Lømo (1973) is now called 'long-term potentiation' (LTP). LTP has been reproduced in many laboratory studies and has been found to be a feature of synaptic excitation throughout the cerebral cortex (Malenka 2003). LTP has been identified in the neocortex, the amygdala, the cerebellum and the neostriatal region of the basal nuclei (Bauer et al. 2007).

It is known that LTP occurs when neurotransmitter released from a presynaptic neuron activates a specific receptor on the postsynaptic neuron called the AMPA receptor, causing inflow of sodium ions and depolarisation at the postsynaptic membrane (Lamprecht and LeDoux 2004). Another receptor in the postsynaptic membrane, the NMDA receptor, is then opened up as a result of the depolarisation, leading to an inflow of positively charged calcium and sodium ions, an event that is believed to facilitate plasticity, in Hebb's sense of increased effectiveness of activation between the pre- and postsynaptic neurons (Eichenbaum 2012; Lamprecht and LeDoux 2004).

The finding that synaptic plasticity requires both presynaptic release of neurotransmitter *and* depolarisation of the postsynaptic membrane has been seen as a confirmation of Hebb's postulate (Bliss and Collingridge 1993; Lamprecht and LeDoux 2004). Furthermore, plasticity has been noted at the level of the structure of the synapse following LTP, as spines, extensions of the dendrites that function to increase the available surface area for inputs from presynaptic cells, have been found to increase in number and also change their shape during LTP (Lamprecht and LeDoux 2004). This suggests a strengthening of the synapse, as predicted by Hebb. Baddeley (2015a) suggests that LTP may facilitate consolidation of the memory trace following initial encoding.

LTP is only observed following electrical stimulation of presynaptic cells in laboratory conditions; however, similar changes have been noticed in animals'

brains following learning, and researchers have found that blocking the NMDA receptor leads to impaired spatial learning in rats (Eichenbaum 2012; Lamprecht and LeDoux 2004). Overall, LTP is felt by many researchers to be a 'universal plasticity mechanism' that provides a model of the neural events that occur following learning and memory formation and that aligns with Hebb's postulate (Eichenbaum 2012, p. 62).

Occupation and Neural Plasticity

For occupational therapists it is crucial to grasp that plasticity is influenced by experience, so what we *do* shapes brain structure. Development is distinguished by 'sensitive periods', in which plasticity is more likely to occur, and 'critical periods', in which deprivation of occupational opportunities impedes neural plasticity with potentially irreversible results (Sanes and Jessell 2013, p. 1260). Evidence for this comes from a study by Eluvathingal et al. (2006), who conducted magnetic resonance imaging (MRI) scans of seven children, with an average age of 9.7 years, who had been raised from birth in Romanian orphanages during the Ceausescu period, where they had been socially and emotionally deprived (Gluck et al. 2008), and who had subsequently been adopted by families in the United States. The control group consisted of seven 'normal' children, with an age of 10.7 years (Eluvathingal et al. 2006). The images were processed using diffusion tensor imaging (DTI), which allows visualisation of white matter tracts in the brain (Eluvathingal et al. 2006). It was found that the left uncinate fasciculus, a tract connecting the anterior temporal and frontal lobes of the brain, had significantly lower fractional anisotropy values for the adopted children, indicating structural deficiencies in the tract. The authors comment that abnormalities in this structure have also been noted in people with schizophrenia, where they have been linked to impaired verbal, episodic and declarative memory (Eluvathingal et al. 2006). This is evidence of how occupational deprivation may affect brain development.

Striking evidence for the way in which occupation influences neural plasticity was also provided by Maguire et al. (2000). These authors scanned the brains of 16 licensed London cab drivers. This occupational group has specific skills: in order to gain their licence, drivers must learn the location of 25 000 streets, training that takes two years (Maguire et al. 2000, 2006). Maguire et al. (2000) compared the scans with those from a control group of non-taxi drivers and found that the taxi drivers had a significantly larger mass of grey matter, the segment of the brain consisting of neuron cell bodies (Tortora and Derrickson 2011), in the posterior hippocampus on both sides (Maguire et al. 2000). In addition, they found that the number of years driving a taxi was positively correlated with the volume of grey matter in the right posterior hippocampus (Maguire et al. 2000). Subsequent research compared taxi drivers with a group of London bus drivers who drove fixed routes that did not require the navigational skills of cab drivers (Maguire et al. 2006). In this study, the authors found a greater volume of grey matter in the right and left mid-posterior regions of the hippocampus in the taxi drivers (Maguire et al. 2006). They interpreted their results as evidence supporting experience-dependent plasticity (Maguire

et al. 2000, 2006). These findings suggest that productivity occupations can shape brain structure.

Historical Theories of Memory

Associationism and Occupation

Aristotle, writing in the fourth century BCE, argued that learning and memory occur as a result of the 'association' of items (Gluck et al. 2008, p. 4). For example, if trying to remember the word 'Autumn', one 'might pass swiftly in thought from one point to another, e.g. from milk to white, from white to mist, and thence to moist, from which one remembers Autumn (the season of mists)' (Aristotle and McKeon, 1941, p. 614). He also believed that we may recollect things more quickly if we think about them 'frequently' or by thinking about things that are similar to those items we are trying to remember (Aristotle and McKeon, 1941, p. 614). This 'associationist' perspective has continued to be influential in memory theory (Tulving and Madigan 1970; Gluck et al. 2008, p. 10).

One person who developed associationism was William James (1890). First, he argued that an item could only be recognised as a memory once it was associated with other items from our past, otherwise it would appear as a kind of dream isolated from any context (James 1890). Second, this association of items with each other constituted the 'elementary law of habit in the nerve-centres' (James 1890, p. 1522). Thus, he stressed that both retaining and retrieving memories depended on the modification of neural pathways shaped by habit and that memory was the conscious aspect of this process; this novel proposal was not adopted by mainstream psychology until many years later (Gluck et al. 2008). Third, retention and retrieval benefited from increasing the number and elaborateness of the associates of the item, with each association giving the person an extra 'hook' to locate the item when trawling the memory (James 1890, p. 1536). Fourth, he argued that memory was strongest for those items linked to our preferred occupations; an athlete, for example, may retain vast knowledge of information linked to their sport, while retaining little of anything extraneous. This occupation-linked memory formed a 'concept-system' that associated otherwise isolated pieces of information together (James 1890, p. 1537).

In the nineteenth century the application of experimental methods to memory research was pioneered by Ebbinghaus, who used lists of nonsense words to test learning, retention and forgetting (Gluck et al. 2008; Schacter 2008). Meanwhile, Semon developed the notion of the 'engram', the fleeting or more long-lasting changes in the brain stemming from experience (Schacter 2008).

Schema Theory

Bartlett, working in Britain in the early twentieth century, referred to the earlier work of Head, who had suggested that conscious awareness of a change in posture was, unconsciously, related to earlier postures (Bartlett 1995). This amalgamation of previous postures, against which the incoming sensation of postural change is evaluated prior to consciousness awareness,

Bartlett (1995, p. 199) labelled a 'schema'. Bartlett (1995, p. 200) objected to the idea of the cortex as a 'storehouse' of impressions of the past, arguing that schemata were constantly active and developing. Applied to remembering in general, Bartlett argued that this meant that memory does not simply reproduce the past, but involves 'construction' on a schema (1995, p. 205). Construction may involve condensing and elaborating items from the past, or even inventing and adding material (Bartlett 1995). This ongoing reconstruction of schemata allows a complex organism to adapt to an ever-changing environment and, in Bartlett's (1995) view, is both the origin of and explanation for consciousness. The elements of the schema that are foregrounded depend less on *when* the experience occurred and more on the 'interests and ideals' that shape the 'attitude' of the person, so that schemata are organised according to 'vocation', or divisions of 'human knowledge', for example (Bartlett 1995, pp. 210, 211, 213). So, in this view, memory traces are not stored passively, but change as our own inclinations change, and are linked to our occupations.

Bartlett (1995) based his arguments on the results of a range of experimental work. In one study, people were shown images of faces of men in military caps. This was done during the First World War and, suggested Bartlett (1995), the memories of the images were influenced by his participants' attitudes. For example, a picture of a 'regular army type' was remembered after a delay as having a moustache, which was not actually in the image; Bartlett (1995, p. 54) suggested that the memory was actually shaped by imported details from cartoons of 'Tommy Atkins', the stereotypical British soldier, which were then popular. In addition, the image of a captain was remembered subsequently as being more angular and serious than was actually the case, and one person, on being shown the original picture once more, initially believed that the experimenter had made a switch (Bartlett 1995). These were examples of what Bartlett (1995, p. 44) called 'effort after meaning', where the person attempts to connect a stimulus with something else, in this case military stereotypes, and which he believed underpinned all human cognition.

In another experiment, participants were asked to read a folk story from North America, 'The War of the Ghosts'; they were then asked to recall the story after 15 minutes, 20 hours and sometimes after several years (Bartlett 1995). With time, Bartlett (1995) noted that the retelling became more concise, the language more modern, and more magical aspects of the tale were missed out. He also noted that when some men remembered the story they tended to foreground details concerning the anxiety of family members of absent warriors; he points out, once more, that these men were tested at the time of the war and their remembering may therefore have been influenced by their own attitudes concerning actual or immanent military service (Bartlett 1995). Bartlett (1995, p. 52) insisted on the adaptive nature of constructive remembering, commenting that in everyday life 'meticulous accuracy of detail' in memory was of little importance. If this view is correct, then it perhaps calls into question the real-world applicability of the standardised cognitive screening tests often used by occupational therapists. Overall, Bartlett's experimental work provides evidence of the ways in which occupation, and awareness of occupational roles, may contribute to the construction of memory.

Information Processing Approaches

Prior to the 1950s, psychology in the United States was dominated by 'behaviourism', an approach premised on the idea that only externally observable behaviours could be meaningfully studied (Miller 2003). In this view, the mental processes underpinning memory, for example, could not be measured, and only learning, which could be observed and controlled, was appropriate for research (Miller 2003). It is important to state that different approaches prevailed in other parts of the world, for instance Bartlett's (1995) research in Britain, described earlier, and Luria's work focusing on the neural process underpinning the mind in the Soviet Union (Luria 1966; Miller 2003). However, Tulving (1983) argues that the decline in memory research throughout much of the twentieth century, despite the early work of Ebbinghaus, Semon and James, resulted from the dominance of the behaviourist approach.

The situation changed in 1956, largely as a result of presentations from researchers in computer science, linguistics and experimental psychology at an interdisciplinary symposium at the Massachusetts Institute of Technology (Miller 2003). In particular, the presentation by Noam Chomsky on language is considered to have had a major impact (Miller 2003; Gazzaniga et al. 2009). The symposium contributed to the analysis of learning and memory as mental *information processing*, an approach that eventually fed into the emergence of cognitive science in the 1970s (Miller 2003). Miller (2003) has described cognitive science as an interdisciplinary field linking neuroscience, linguistics, anthropology, computer science, psychology and philosophy. One result of this 'cognitive revolution' seems to have been an increase in research on memory, as Melton (1963) noted a large increase in published experimental work from 1958 onwards.

A parallel development was the use of analogies from computer science. Melton (1963, pp. 7, 12), whose earlier experimental work had been sponsored by the US Army Electronics Command, for example, argued that memory theory should be seen as a subfield of learning theory that focused on 'storage and retrieval of memory traces' and he also used the term 'encoding'. These concepts have become part of the toolkit of cognitive neuroscientists, with the key stages of the information processing model of learning and memory being *encoding*, as the sensory stimuli are converted to neural representations; *storage*, as the representations are permanently cached for later extraction; and *retrieval*, when they are retrieved for use (Gazzaniga et al. 2009). Encoding is divided sometimes into two further steps: *acquisition*, where sensory inputs are temporarily stored and analysed; and *consolidation*, where these representations are fortified with time (Gazzaniga et al. 2009). Tulving (1983) argues that the application of these 'two principles' of encoding and retrieval led to a renaissance in memory research following the era of behaviourism.

One of the key contributions in this new area came in an article by Miller (1956) that explored constraints on learning and memory in relation to information processing. In this account, a communication system requires a connection between input and output. The degree of correlation between input and output is an index of the degree to which the output is related to the input and how much output is down to random variation, or 'noise', in the system (Miller 1956, p. 82). In experiments where a person was asked

to make judgements on different stimuli, the individual was conceived of as an 'information channel' (Miller 1956). A unit of information was defined as the amount of information needed to halve the degree of uncertainty in a situation where there are two equally possible alternatives, meaning that the chances of accuracy are 50 : 50 (Miller 1956; Schmidt and Lee 2005). The unit of information was expressed as a binary digit or 'bit' (Miller 1956, p. 82; Schmidt and Lee 2005). One bit allows us to choose between two alternatives, two bits between four, three bits between eight and so on, meaning that each doubling of the number of choices requires one extra bit of information (Miller 1956). The upper boundary of the amount of information a person can process when asked to make judgements about stimuli, the point at which confusion starts to occur, is called 'channel capacity' (Miller 1956, p. 82).

Miller (1956) surveyed the results of a number of studies of discrimination over a range of modalities, including loudness levels, degree of curvature of visually presented lines and salt content of water when tasted, and estimated that the mean channel capacity was about 2.6 bits, meaning that the upper limit for categorisation was about 6.5 items. He suggested that these limits may be a function of the human nervous system or of learning processes (Miller 1956).

Miller's (1956) concepts have application to the work of occupational therapists, when recommending strategies for people with memory impairments. In a personal care task, for instance, the occupational therapist might recommend a carer to reduce the number of choices the person with dementia needs to make by laying out their clothes for them in advance, thus cutting the number of bits of information needed to complete the task. A simplified representation of this is shown in Table 1.1.

Table 1.1 gives examples of instructions that could be used in a dressing task. In line with Miller's (1956) theory, one bit is needed to choose between two alternatives and two bits are needed to choose between four alternatives. By decreasing the number of alternatives, the occupational therapist can reduce the amount of information, or bits, needed to carry out the task. Alternatively, the therapist could increase the number of bits needed by increasing the number of alternatives. This approach would allow the therapist to grade the task for a person with memory impairment, according to their capacity.

Another of Miller's concepts that has relevance for occupational therapists originated from his work on the 'span of immediate memory' (Miller 1956, p. 92). He argued that this was limited by the number of 'chunks of information' to be memorised, which seemed to be unaffected by the quantity of bits in each chunk. Miller (1956, p. 93) maintained that this independence resulted from

Table 1.1 Instructions in a personal care task in relation to bits of information required to respond correctly.

Statement	Number of bits required
'Put your shirt on'	0
'Put on your red shirt or your blue shirt'	1
'Put on your red shirt or your blue shirt or your white tee-shirt or your red tee-shirt'	2

'recoding', whereby the initial code, which had a large amount of information organised into a lot of chunks, was recoded so that there was a smaller number of chunks but more bits in each chunk. He argued that the easiest way to do this would be to recode the original inputs by labelling them with a name and remembering the name in place of the inputs (Miller 1956).

Miller (1956) suggested that humans were recoding information into chunks almost constantly in daily life and that this process underpinned the majority of mnemonic techniques and could actually be equivalent to memorisation itself. Melton (1963, p. 11) was later to describe Miller's concept of the chunk as 'the unit of measurement of human information-processing capacities'. Miller also suggested that verbal recoding was a reflection of the individual's life history, in that it depended on their particular inclinations and was actually the 'life-blood' of thought (Miller 1956, p. 95). In this sense, then, recoding is, in part, a function of our occupational history. In addition, occupational therapists can apply 'chunking' when adapting activities for people with memory impairment, for example by grouping the tasks required in preparation of a complex hot meal under the labels of 'preparation', 'cooking', 'serving' and 'safety'. This is illustrated in Table 1.2. In addition, the concept of chunking will be encountered in more detail again in Chapter 5.

Despite the use of analogies from computing, the information processing approach to learning and memory was *not* based on a model of the person as a non-conscious device. This has also been stressed by other authors. Occupational scientists, for example, have insisted that the human person responds to an environment that challenges them at various levels, including the 'symbolic-spiritual', via occupational engagement (Yerxa 2000, p. 197).

Table 1.2 Chunking the tasks required to make hot tea and beans on toast.

Chunk	Tasks
Preparation	Put bread in toaster
	Open can of beans
	Fill kettle with water
	Plug in toaster
	Put tea bags in teapot
	Take pan and plate out of cupboard
Cooking	Place beans in pan and switch on hob
	Pull lever down on toaster
	Switch kettle on to boil water
	Pour boiled water into teapot
Serving	Place toast on plate
	Pour beans onto toast
	Pour tea into cup and add milk
Safety	Do not put hand near lit hob
	Do not put fingers in toaster
	Turn off hob
	Unplug toaster

Luria (1973, p. 284), a pioneer of neuropsychology, also stressed that encoding was an *active* process whereby the person chooses the 'system' that would complete it, while recall of information was a 'complex and active' process involving selection of relevant items according to 'the purpose of the task' in hand. Similarly, as shown later, early work in the cognitive science tradition also provided evidence for the active nature of memory.

Levels of Memory Processing

Craik and Lockhart (1972) produced a critical view of contemporary memory research. They took issue with the contemporary 'multistore models', based on computer analogies, of memory that portrayed items as passing through a sensory (SS), short-term (STS) and long-term store (LTS) (Craik and Lockhart 1972, p. 671). SS was a transient store, which operated independently of whether the person was paying attention to the stimulus or not; STS required attention to the stimulus, had a limited capacity and stored information in a manner specific to the sensory modality of the stimulus, so that the storage format mirrored that of the input; and LTS was thought to have an unlimited storage capacity and items were stored related to meaning, in a 'semantic' format (Craik and Lockhart 1972, p. 672).

Craik and Lockhart (1972, p. 671) argued that some of the assumptions of these 'multistore models' could be questioned. STS, for example, had been shown to store semantic as well as modality-specific items. In addition, estimates of the rate of decay of items in STS varied widely, with research showing that a visual stimulus could persist for anywhere between 1 and 25 seconds. They also cited evidence that people could recognise non-verbal but relatively non-semantic items, such as faces and voices, over long periods, calling into question the nature of long-term storage. All this suggested that the demarcations of the multistore models could be questioned.

Craik and Lockhart (1972) proposed that research on encoding and retrieval should focus on the *level* of processing. Their concept was that a perceived stimulus moves through stages of processing, from basic sensory and physical features to association with prior learning, and recognition of patterns and semantics. In this view, greater depth of processing implies more cognitive and semantic analysis. Coding may also be 'elaborated', meaning that an item may be linked to images or other associations based on the person's experience (Craik and Lockhart 1972). Also, these authors redefined the 'memory trace' as resulting from perceptual analysis, while its longevity is a function of the depth of processing, such that deeper processing leads to longer retention (Craik and Lockhart 1972, p. 675). Furthermore, a cue to retrieve an item would be more effective if it matched the initial coding, meaning that the original 'learning context' could be restored (Craik and Lockhart 1972, p. 678). Craik and Lockhart's (1972) views point to a role for personal experience in shaping the encoding process, and align with the suggestions of occupational scientists that memory may act as a 'buffer' between genes and culture on one side, and behaviour on the other, and also that a person's interests and history of 'engagement in occupation' shape the development of their nervous system (Wilcock 2006; Yerxa 2000, p. 197).

A widely discussed early study focusing on encoding and retrieval was carried out by Craik and Tulving (1975). These authors suggested that their work was part of a 'new look in memory research', in that it focused on the 'mental operations' conducted on the stimulus by the person, rather than the properties of the stimulus; this focus resulted from a belief that differences in retention reflected different encoding strategies (Craik and Tulving 1975). They suggested that, just as perception can progress from basic awareness of sensation to high-level semantic processing, so material to be memorised could be analysed at different levels and retention was a function of the level of elaboration of the analysis. This meant that material processed only at the sensory level would be less well retained than material analysed with greater attention and elaborated with associations and images (Craik and Tulving 1975).

Craik and Tulving (1975) ran experiments in which participants were questioned about a word presented for encoding. Questions were asked about words at three different levels: structural (e.g. is it written in upper case?); phonemic (e.g. does it rhyme with 'crate'?); and semantic (e.g. is it an animal name? Would it fit in this sentence?). They were then shown the word for 200 milliseconds and asked to answer yes or no to the question. Following this, their retention of the words was tested, without warning, in conditions of 'free recall', where the person simply listed recalled words in any order; 'cued recall', where a fragment of the initial 'word event' was provided as a cue; or 'recognition', in which the initial words were viewed alongside 'distractors' that were not part of the original presentation (Craik and Tulving 1975, p. 272).

The results showed that semantic decisions took slightly longer than structural decisions (Craik and Tulving 1975). Taking processing time as an index of depth, Craik and Tulving (1975) argued that the longer processing time was a function of the depth of processing. Crucially, the words presented with semantic questions were recalled better than those presented with structural or phonemic questions, and the authors concluded that this manipulation of the level of processing had affected the strength of retention (Craik and Tulving 1975).

Craik and Tulving (1975) argued for the concept of 'spread', rather than depth, as a key determinant of retention. This suggests that the stimulus can be elaborated by structural, phonemic or semantic coding (Craik and Tulving 1975). Preservation of memory, then, depends on the quality of encoding, so that a basic analysis of semantics is more effective than a complex analysis of structure (Craik and Tulving 1975). 'Memory performance', in this view, is a function of how elaborate the encoding is and the 'memory trace' is, in fact, the history of the observer's cognitive analyses of the stimulus (Craik and Tulving 1975, p. 290).

Another important finding was that retention was improved when the coding question or context was congruous with the target word, so that the two form a single unit, and the authors suggested that this explained the higher retention of words that required a positive response in their experiments (Craik and Tulving 1975). In addition, Craik and Tulving (1975) argued that congruity meant that retrieval of only a part of the presented stimulus allowed more rapid access to the entire memory. Furthermore, they suggested that this 'unitising' of stimulus and context may involve coding the item in relation to the person's world knowledge, their 'semantic

memory', meaning that when they encounter a cue they can draw on these structures and construct the primary coding once more (Craik and Tulving 1975, p. 291). This idea seems congruous with Bartlett's concept of 'effort after meaning' (1995, p. 44), described earlier.

For occupational therapists in clinical practice, these ideas can be applied when considering how instructions are presented to a service user, or a team member in training. For example, asking a patient with memory impairment to explain each of the steps involved in a kitchen activity prior to practice, rather than the therapist simply listing the different tasks, may facilitate deeper and more elaborate processing, aiding recall. For occupational therapists involved in education or training, encouraging the student or supervisee to work through problems on their own may have a similar impact. (The author has successfully applied these principles to the teaching of anatomy and physiology to year one undergraduate occupational therapy students.) Overall, the message is that more active engagement with the information facilitates better encoding and retrieval.

The Case of Henry Molaison

As well as the experimental work already discussed, important insights into learning and memory have come from clinical case studies. One historically significant case is discussed here, while another will be discussed in Chapter 3.

In 1953, a 27-year-old man, Henry Molaison from Hartford, Connecticut, in the United States, underwent brain surgery. His case, known as that of 'H.M.' until his death in 2008, was to become one of the most widely cited in the field of neuroscience, and was to open the contemporary era of memory investigation by providing the first evidence that memory could be separated from other perceptual and cognitive brain functions and also localised to specific brain regions (Corkin 2002, 2013; Squire 2009).

At the age of either 7 (Corkin 2002; Eichenbaum 2002, 2012; Squire 2009) or 9 years old (Scoville and Milner 1957; the confusion may result from inconsistencies in medical records and family accounts: Corkin 2013), Molaison had struck his head and lost consciousness after being knocked over by a bicycle, and a few years later he started experiencing mild epileptic seizures. Whether these resulted from the fall or from inherited genetic factors is not clear, but certainly by early adulthood the seizures had become frequent and severe, marked by 'urinary incontinence, tongue biting and loss of consciousness' leaving him 'unable to work' (Scoville and Milner 1957 p. 11; Eichenbaum 2002).

Although doctors could not identify a regional source of the epileptic discharges, evidence suggested that the medial temporal lobes were, often, the origin of such activity (Corkin 2013). Accordingly, a neurosurgeon, William Beecher Scoville, proposed bilateral removal of a brain region called the hippocampus, which is located in the floor of the medial temporal lobe (Scoville and Milner 1957). Molaison gave consent, and 5 cm of the medial temporal lobes, including the anterior hippocampi, anterior parahippocampal gyri encompassing the entorhinal, perirhinal and anterior parahippocampal cortices, and the amygdalae, were removed (Corkin 1968, 2013; Squire 2009). (Scoville (1968) stated that 8 cm of the lobe had been removed; however, subsequent

neuroimaging showed that this was incorrect.) The amygdala, as part of the limbic system, is discussed in detail in Box 1.4 later in the chapter.

Following the operation, although the epileptic seizures subsided, he began to display marked memory impairments: he could no longer find his way around the ward, could not remember having eaten lunch half an hour earlier or people he had just met, and only seemed vaguely aware of having had surgery (Scoville and Milner 1957). He had developed comprehensive anterograde amnesia that persisted when researchers used different types of tests, with varied stimuli, from words to faces and public and personal episodes, and in every sensory domain (Corkin 2002).

The profundity of this amnesia is shown by Milner et al. (1968), who describe Molaison visiting his mother, who was his main carer, while she was in hospital, three times in one week. When tested, he had no memory of this, despite one visit having happened that morning. He did express a sense of unease that there may have been a problem with one of his parents, but by the next day he seemed to have forgotten this altogether and did not evidence any emotion in connection with the worry he had mentioned (Milner et al. 1968). Corkin (2013) commented that, in this situation, Molaison had forgotten the fact that his mother was in hospital, but seemed to retain the emotional salience, leading to his sense that something was wrong. In later life, he showed only vague awareness that his father had died. His mother eventually developed dementia and moved to a care setting and, in 1977, a researcher noted that Molaison carried a note in his wallet stating 'Dad's gone . . . Mum's in nursing home' (Corkin 2013, p. 205), to remind him of these important personal events.

Molaison likened his state to that of just waking from a dream (Milner et al. 1968). Milner et al. (1968) commented that it was as if he were approaching awareness of his circumstances but was unable to completely understand them, as he had no memory of what had happened previously. This temporal disorientation is illustrated by an exchange with a researcher in 1992: asked what he had done that morning, or what he had had for lunch, he could not answer; asked what he would do the next day, he replied 'whatever's beneficial' (Corkin 2013, p. xiii). The reader will be reminded of William James's (1890) speculation, explained earlier, about the dreamlike state that would result if one were unable to associate items with other memory traces.

Molaison's amnesia was predominantly anterograde; that is, it was for events occurring *after* his lobectomy. He did have some degree of retrograde amnesia for one to two years prior to surgery, but his memory for events prior to this was mainly intact (Milner et al. 1968). Once, for example, when directing researchers to his home, he guided them to the house he had lived in *before* the operation (Milner et al. 1968). He also knew his date of birth, but could not state his age, and remembered events from his first years in school and a job he had had in his 20s (Milner et al. 1968).

Molaison maintained good language abilities: he could work with complex sentences and was able to understand and make jokes (Corkin 2013; Milner et al. 1968). The intersection of vocabulary knowledge and amnesia was shown dramatically in an experiment involving 'word stem completion priming', where he was given a list of words to study, then shown a list of word stems that include both studied and non-studied words. Priming, a form of 'implicit' or 'non-declarative memory' in which learning takes place without conscious

recollection, would be evidenced if he were able to complete the word stems of the studied words more rapidly (Gazzaniga et al. 2009, p. 338; Postle and Corkin 1998). Molaison was presented with a list of study words that had been introduced in US dictionaries only *after* 1965, several years subsequent to his surgery, such as 'jacuzzi' (Corkin 2002). He was then presented with a list of word stems to complete, but showed no evidence of a priming effect for the studied words (Postle and Corkin 1998).

The authors suggested that this was evidence that priming of word stem completion in people with amnesia, a form of *implicit* memory, must rely on 'modification' of a memory representation of the word from before the onset of amnesia, during the study stage of the test. Molaison's lack of memories for words introduced following his surgery meant that the priming effect was absent because there were no memories to modify (Postle and Corkin 1998, p. 433). In a following trial, Molaison was tested for priming using a study list of words appearing in the dictionary *prior to* his operation in 1953. Here, the word stem priming effect was present and was similar to that of non-amnesic control participants (Postle and Corkin 1998).

Despite this marked anterograde amnesia, some domains of memory appeared, remarkably, unimpaired. In one experiment, conducted when he was 40, he was required to maintain a stylus on a target on a rotating disc; in another he had to maintain a stylus bimanually on two tracks on a rotating drum, using both left and right hands together (Corkin 1968). Molaison was able to learn the tasks and showed significantly improved performance when tested over several days (Corkin 1968). At the age of 60, he learned to trace a star when the only visual guide was the view of his hand and the pattern being copied in a mirror (Gabrieli et al. 1993). He was able to achieve this, and the researchers found that he had retained this skill when tested one year later; this was despite him having hardly any recall of having learned the skill and failing to recognise the task even on the first day of practice (Gabrieli et al. 1993). In later life Molaison developed osteoporosis, suffered fractures and had a hip replacement. Despite having no memory of being in hospital or of having osteoporosis, he was still able to learn to use a walking frame (Corkin 2013). These discoveries showed that learning and maintenance of visual-motor abilities do not depend on the medial temporal lobes, which had been removed by the surgery (Corkin 2002).

The key findings from Molaison's case were, first, that the medial temporal lobe – that is, the hippocampus and surrounding regions, discussed in detail in Box 1.1 – is essential for converting immediate items into long-term memory (Squire 2009; Milner et al. 1968). Second, the fact that Molaison had good capacity for retaining information over a short period, for example when remembering digits or in conversation, until he stopped attending to the task, confirmed the distinction between immediate memory and long-term memory (Squire 2009). Squire (2009) points out that an associated finding was that immediate memory is not, primarily, based on the length of time that items can be retained, but on the storage capacity of the system and the ability of the person to attend to the information. The third finding was that memory is not unitary but made up of different systems, in this case 'declarative' memory, of which we are consciously aware, and 'procedural' memory, such as the visual-motor skills Molaison learned, of which we may not be aware

(Eichenbaum 2012; Squire 2009, p. 8). Fourth, because he was found to have intact memories from up to two years prior to surgery, it suggested that the medial temporal lobe region was not the site where such long-term information was stored (Squire 2009).

BOX 1.1 THE STRUCTURE AND FUNCTION OF THE HIPPOCAMPUS

The 'hippocampal memory system' is located within the medial temporal lobe of the cerebrum (Eichenbaum 2012, p. 236). It consists of the hippocampus, which is made up of the dentate gyrus, the subiculum and the horn of Ammon. The latter section is subdivided into four regions, CA1, CA2, CA3 and CA4 (CA stands for 'cornu ammonis', or 'horn of Ammon') (Eichenbaum 2012; Gazzaniga et al. 2009). It should be noted that there is some variation in the terminology that authors use, and the hippocampus is also described as consisting only of CA1–CA4, while the hippocampus, dentate and subiculum together are referred to as the 'hippocampal formation' (Amaral and Strick 2013, p. 349).

The parahippocampal region comprises the perirhinal cortex, the parahippocampal cortex and the entorhinal cortex (Bear et al. 2016; Eichenbaum 2012). The hippocampus and these linked cortical regions make up the floor of the lateral ventricle's temporal horn and are located within the ventromedial aspect of the temporal lobe (Gazzaniga et al. 2009; Amaral and Strick 2013).

The location of the hippocampus in the cerebrum is shown in Figure 1.1.

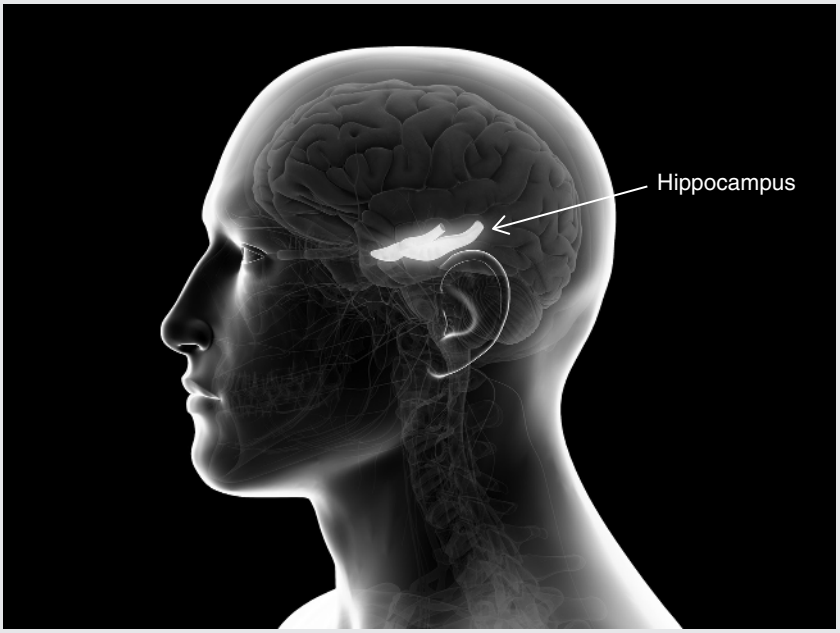


Figure 1.1 Location of the hippocampus in sagittal view of the brain.
Source: SciePro/Adobe Stock.

The parahippocampal region is involved with 'bidirectional' communication with neocortical areas and with the hippocampus (Eichenbaum 2012, p. 237). The various areas of the parahippocampal region receive information that has been highly processed by the different neocortical areas, ultimately by the cerebral association areas of the parietal, temporal and frontal lobes, meaning that only high-level representations based on 'visual, auditory, and somatic' information, rather than basic sensory inputs, are received (Kandel et al. 2000, p. 1231; Bear et al. 2016). These are transmitted to the hippocampus for further processing and then returned to the parahippocampal region, from where they are relayed back to the same neocortical regions they first came from (Eichenbaum 2012). The key function of these medial temporal lobe regions is to modify, reorganise and improve storage of information represented in the neocortex (Eichenbaum 2012).

The hippocampus is connected to subcortical brain regions, including the thalamus and hypothalamus, via a white matter bundle called the fornix, and to the neocortical areas by way of the parahippocampal region, mainly via the entorhinal cortex (Eichenbaum 2012). The entorhinal cortex projects to the dentate gyrus via an axon bundle called the perforant path (Kandel et al. 2000, p. 1231; Bear et al. 2016). The dentate gyrus then projects axons called mossy fibres to CA3, which in turn projects one branch of axons to the fornix and another branch, called the Schaffer collateral, to CA1 (Bear et al. 2016). The parahippocampal cortex and fornix are shown in Figure 1.3 later in the chapter.

The hippocampal 'return circuit' involves projections to subcortical regions via the fornix, and also projections from CA1 and the subiculum back to the parahippocampal region, particularly the entorhinal cortex. From there, projections from the entorhinal and perirhinal cortices relay the information back to the neocortical regions from which the signals first came (Eichenbaum 2012, p. 241). The principal theme here is that signalling from the neocortex affects the parahippocampal region and the hippocampus and the processing of the signals that takes place in these areas in turn influences the neocortex (Eichenbaum 2012).

As shown in the case of Henry Molaison, damage in the hippocampus impairs the ability to convert short-term memories in order to form new long-term memories (Amaral and Strick 2013). In addition, damage to CA1 is a feature of Alzheimer's disease, a key feature of which is memory impairment (Padurariu et al. 2012).

Taxonomies of Memory

Researchers have developed models of the human memory system, many of which are based on the work carried out with patients such as Henry Molaison (Corkin 2013; Eichenbaum 2012). Insights from these models can inform occupational therapists' practice with individuals with memory impairment. They are discussed in the following section.

Tulving's Hierarchy of Procedural, Semantic and Episodic Memory

Tulving (1985a, p. 386) conceived of memory as a 'complex' that could be subdivided into three 'memory systems' consisting of brain mechanisms and their associated cognitive skills and behaviours. The systems were organised hierarchically: 'higher' systems depended on a 'lower' system or systems, but also possessed specific capacities that the lower system did not (Tulving 1985a). Tulving (1985b) listed the systems, in order from lower to higher, as procedural, semantic and episodic memory. In Tulving's scheme, procedural memory underpins semantic, and semantic underpins episodic, so one can have procedural memory without semantic and episodic, and semantic without episodic, but not the other way round (Tulving 1985b). These memory systems are discussed in more detail next.

Procedural memory involves gaining, retaining and using skills of perception, movement and cognition (Tulving 1985a). It underpins the learning of appropriate responses to stimuli, which may be arranged in complex patterns and require chained responses (Tulving 1985a).

Acquiring procedural memory necessitates an observable behavioural response (Tulving 1985a). It does not require any memory of the context in which knowledge was acquired, but prescribes a pattern for action when the stimulus is encountered again (Tulving 1985a). This means that procedural memory can only be expressed through the performance of the learned response (Tulving 1985b).

Tulving (1985b, p. 3) also argued that procedural memory is accompanied by 'anoetic' consciousness, which does not require knowledge of anything beyond the stimulus. An example might be the skill of riding a bicycle. Here, the performance of the skill does not require us to remember the event of learning it, and does not necessitate any additional information about the world in order to perform it. In addition, procedural memory may support the motor and process skills identified by Kielhofner (1995), such as postural alignment, calibration of the necessary force or speed, or organisation of the tools and space needed to complete a task or activity.

Semantic memory encompasses information about the world that can be represented internally using symbols (Tulving 1985a). The information units of semantic memory may be 'facts', 'ideas', 'concepts', 'rules', 'propositions', 'schemata' and so on (Tulving 1983, p. 38). Although no specific behavioural response is required during semantic memory performance, the memory could potentially be expressed in a variety of ways, not necessarily aligned to the manner and circumstances in which it was acquired (Tulving 1985a).

Semantic memory is associated with 'noetic' or 'knowing' consciousness, which facilitates mental operations on items and events that are no longer present in the outside world (Tulving 1985b, p. 3). To return to the example of riding a bicycle, knowledge of the meaning of road signs, traffic lights and the different types of cycles would be part of semantic memory. We could, for instance, understand the messages of signs while on the road, which are conveyed visually, but we could also explain their meanings using words or drawing to another person in a room with no view of the signs. Semantic memory is also

needed to complete daily living tasks, for example by providing the knowledge needed to recognise items such as a kettle or cooker.

Episodic memory, first proposed by Tulving in 1972, entails the recollection of events we have experienced ourselves (Tulving 1985b, 2002). This starts with a person 'witnessing or experiencing' an 'event or episode' and finishes when they subsequently remember it (Tulving 1983, p. 11). The episodic memory mode allows us to mentally travel back in time; its correlate is 'autonoetic' or 'self-knowing' consciousness, which imbues the act of remembering with the feeling that we did truly experience the event (Tulving 1985b, p. 1). Autonoetic consciousness gives the person an awareness of their identity and location in time as someone with a past and a future (Tulving 1985a).

Drawing on cycling once more, we may have a clear episodic memory of the first time that we rode a bike without stabilisers; this could involve memories of the person helping us, the location it occurred and our feelings as it happened. Autonoetic consciousness also involves 'subjective time', the capacity to be aware of our past, while also imagining ourselves in the future (Tulving 1985b; Hassabis and Maguire 2007). Thus, episodic memory and autonoetic consciousness allow an organism to act more decisively in the present and plan more efficiently for the future.

Occupational therapy authors have also highlighted the 'temporality' of the experience of human occupation (Kielhofner 1995, p. 3). Kielhofner (1995), for example, presented a rudimentary definition of human occupations as activities with cultural meaning that develop through time, imbuing human experience with the sense of past and future. Other occupational therapy theorists have used the concept of 'becoming' to show how humans change in time as they aspire to achievements that require engagement in occupation (Hitch et al. 2014). Law et al. (1996) also stressed the temporal nature of occupations as grouped actions undertaken repeatedly as part of a role, potentially throughout life, in order to meet inherent personal needs. Arguably, then, episodic memory and autonoetic consciousness would be involved in providing the sense of personal continuity that would allow occupations defined in these ways to be undertaken.

Episodic memory also has an affective element, which semantic memory does not; the mood of the person during the remembered experience is part of the trace of the memory and is also important when retrieving the memory (Tulving 1983). An interesting application of these concepts is in 'Gibbs' Reflective Cycle', a tool used by some occupational therapy practitioners to support reflective practice. Here, the therapist is asked to think about a specific episode, usually a critical incident from clinical experience, remember their feelings as it happened, and think about what they would do if the same situation occurred again, an example of 'memory for the future' (Tulving 1985b; Hargreaves and Page 2013). This is an instance of drawing on episodic memory in order to support effective reflection.

Another clinical case, that of 'K.C.', provided evidence that episodic memory could also be considered a separate domain (Rosenbaum et al. 2005). At the age of 30, K.C. was involved in a motorbike accident that left him with head injuries (Rosenbaum et al. 2005). MRI scans revealed extensive bilateral damage in the hippocampal formation and the parahippocampal gyrus, and damage to other

regions thought to be involved with memory, including the left amygdala and left mamillary bodies (Rosenbaum et al. 2005).

K.C. did not show evidence of general cognitive impairment and was able to learn new procedures such as basic computer programming (Rosenbaum et al. 2005). His memory for semantic items learnt prior to the injury was intact (Tulving 2002). He was also able to learn new semantic information, for example he could remember novel definitions of everyday words that the researchers taught him, although he had no recollection of the learning event (Rosenbaum et al. 2005; Tulving 2002). However, K.C. was unable to recall any episodes from his life (Tulving 2002). For example, he could not remember being told of the death of his brother, to whom he was very close, nor a fall that led to surgery and using crutches for six months, nor being forced to evacuate his house following a local chemical spill (Rosenbaum et al. 2005; Tulving 2002).

K.C. also had an impaired sense of himself as a person in time and could not make statements about his future: when asked to think about what he might do the following day, he described his mind as 'blank' (Tulving 1985b, 2002). This is comparable to Henry Molaison, who commented on one occasion that 'every day is alone in itself, whatever enjoyment I've had, and whatever sorrow I've had' (Milner et al. 1968, p. 217). Following Tulving (1985b, p. 5), it could be argued that K.C. and Molaison were incapable of the 'mental time travel' that is a function of episodic memory and did not possess 'autonoetic consciousness'.

Schacter et al. (2007) stress that 'episodic thought' can encompass the future as well as the past, referring to evidence that people with amnesia have been found to have reduced ability to imagine novel events in detail (Schacter et al. 2007). Older people have also shown impaired capacity for episodic reminiscence and for generating episodic content when imagining future happenings (Schacter et al. 2007). Schacter et al. (2007) therefore argue that imagining future events depends on the recombination of past memories, and put forward a 'constructive episodic simulation hypothesis' suggesting that imagination of future happenings is dependent on the recombination of previous memories (Schacter et al. 2007, p. 659).

It may be the case that Molaison and K.C. had a diminished sense of personhood, which, as Farah (2010, p. 296) has argued, may include 'self-awareness' and 'cognition about the future'. Occupational therapy theorists such as Wilcock (2006, p. 153) have also foregrounded the drive to order experience over time as a feature of personal 'becoming'. Kielhofner (1995, p. 30), meanwhile, explained how reflection on past experience supports the 'self-knowledge' that allows a person to project themselves into the future and make choices to engage in specific occupations. It appears that neither K.C. nor Henry Molaison was able to do this, suggesting that episodic memory may be a key component of personhood and 'occupational choice' (Kielhofner 1995, p. 30).

The Relationship Between Episodic and Semantic Memory

The registering of information in episodic memory is directly based on experience, while in the semantic system registration is symbolic, for example using language (Tulving 1983). The encoding stage of episodic memory consists of converting information about the episode, including knowledge of when and where it occurred, into a 'trace' or 'engram' (Tulving 1983, p. 11).

We may retrieve knowledge of the past from episodic or semantic memory systems, or a combination of both. The experience is different in both cases: for (Tulving 1985b), episodic retrieval is autonoetic 'remembering', while semantic retrieval is noetic 'knowing'. The experience of recollection is, then, governed by the degree of episodic and semantic information involved in retrieval and a 'trade-off' exists whereby access to poorly remembered episodes can be supported by semantic cues, and impaired semantic cues are strengthened by episodic remembering, a process described as 'synergistic ecphory' (Tulving 1985b, p. 7). 'Ecphory' is a term coined by Semon and indicates 'the process of activating or retrieving a memory' (Schacter 2008, p. 57). An example can be drawn from the case of Henry Molaison: when asked to retrieve episodes relating to celebrating Christmas, he responded with semantic information about the difference between festivities in the south, where his father was born, and the north, where Molaison was brought up (Corkin 2002).

Vulnerability of Episodic Memory

Tulving (1985b, 2002) suggests that episodic memory and autonoetic consciousness are uniquely human. In addition, he argues that they are not present in children under the age of four, but develop later. Furthermore, episodic information is more subject to change, modification and loss, and is therefore selectively vulnerable in amnesia (Tulving 1983). This may be because of the complexity of the information, being based on many combinations of elements, its looser organisation and its basis in a single event (Tulving 1983).

Tulving (1985b) described a patient, N.N., with a closed head injury who could not recall any incidents from his past. His procedural and semantic memory were intact but his episodic was markedly impaired. He had, for example, abstract knowledge of concepts related to time, but no personal sense of time (Tulving 1985b). When asked to describe what he would do tomorrow, or what he did yesterday, he described only blankness (Tulving 1985b). Tulving calls this lack of subjective time awareness 'chronoagnosia', stating that N.N. was living in a 'permanent present' (Tulving 1985b, p. 4). He had anoetic and noetic consciousness but not autonoetic consciousness (Tulving 1985b). N.N. was incapable of 'mental time travel' and the lack of awareness of his past also meant he could not project into the future (Tulving 1985b). It may be recalled that Henry Molaison showed a similar inability to describe past events or to predict what he might do the following day.

Hassabis and Maguire (2007, p. 299) develop these themes, and suggest that 'self-projection' into the future requires a shunt in perception from one's immediate situation to a different, imagined alternative, while maintaining the focus on oneself. They suggest that episodic recollection, future self-projection, navigation and imagination of fictional scenarios all share 'scene construction' as a shared process (Hassabis and Maguire 2007, p. 299). This is characterised by retrieval of information from brain areas specialised for specific sensory modalities and assembly of this into a coherent spatial scene that can be manipulated and also allows visualisation (Hassabis and Maguire 2007, p. 299).

Hassabis and Maguire (2007, p. 300) hold a 'constructivist' view of episodic memory, meaning that recollection involves reconstruction of scenes, not perfect recall. They argue that episodic memory, memory for previously

remembered fictitious events and creation of new fictions activate the hippocampus and other regions, including the posterior parietal cortex and ventromedial prefrontal cortex, and show that patients with bilateral damage to the hippocampus have reduced ability to imagine novel fictitious happenings (Hassabis and Maguire 2007). Furthermore, while non-mnemonic cognitive functions might also depend selectively on processes such as autonoetic consciousness, those linked to the sense of self and scene construction, episodic memory is posited to draw on all these. This complexity may explain why it is peculiarly vulnerable, compared with other memory processes, if the brain is damaged and also why it only emerges at around 4 years old (Hassabis and Maguire 2007).

Episodic Memory and Human Occupation

The concepts of episodic memory and autonoetic consciousness fit well with the notion of 'temporality' as applied to human occupation (Hitch et al. 2014, p. 239). This, in turn, can be associated with Wilcock's (2006, p. 148) concept of 'becoming', referring to the unending process of change, negative as well as positive, that occurs throughout the human lifespan. In addition, it may the case that 'becoming' is a process supported by a wider network of family and community (Hitch et al. 2014). For example, episodic memory impairment is a prominent feature of Alzheimer's type dementia (ATD) and also retrograde amnesia following traumatic brain injury (TBI) (Chatzikostopoulos et al. 2022; Kopelman 2002). It may the case that occupational therapists can encourage family members or carers of people with these conditions to support retrieval of episodic memories with items such as photographs, aromas, music or food. These ideas are revisited in Chapter 7, in relation to interventions such as cognitive stimulation therapy.

Working Memory

Working memory is the capacity for temporarily remembering information and actively processing it at the same time, in order to accomplish an immediate goal (Baddeley 2015b; Corkin 2013). It is conceived of as a 'mental workspace' where action, perception and long-term memory interact (Baddeley 2003; Corkin 2013, p. 65). Occupational therapists' concern with the environment-bound performance of goal-directed, purposeful tasks and activities means that working memory concepts are especially relevant to their practice (Law et al. 1996; Kielhofner 1995). Several accounts of working memory have evolved and some of these are explored next.

The Atkinson and Shiffrin Model of Working Memory

The term 'working memory' was first used by Miller et al. (1960, p. 65) to describe a rapid access storage site for plans that were under formation, transformation or execution, and also for 'intentions', the yet-to-be completed aspects of any interrupted plans. Atkinson and Shiffrin (1968) developed these ideas and proposed a three-part structure for memory consisting of a 'sensory register', where information is held very briefly in the sensory modality in which it was encountered, prior to dissolution; and short-term and long-term stores.

It is perhaps important to stress that, up to this time, it was widely believed that memory was not divisible into short- and long-term components, and Atkinson and Shiffrin's (1968) paper, which drew on analogies from computing and cited Milner's work with Henry Molaison and other hippocampal patients as evidence, played an important role in establishing this division.

In Atkinson and Shiffrin's model, the short-term store constitutes working memory and it accepts items copied from both the sensory register and the long-term store. These are then worked with so as to guide ongoing actions. Items in the short-term store had a life of around 30 seconds, but this could be extended by 'control processes' that the person deploys voluntarily (Atkinson and Shiffrin 1968, p. 14). Such processes could include a range of mechanisms. Rehearsal of the information, for example, could strengthen coding and storage and act as a temporary 'buffer', such as when we repeat a telephone number to ourselves while dialling in order to remember it (Atkinson and Shiffrin 1968, p. 111). The authors also mention chunking of information, which was discussed earlier in this chapter. In addition, they describe the use of mnemonic devices, such as forming visual images of items to aid recall (Atkinson and Shiffrin 1968). Hopefully, it is clear that, in both Miller et al. (1960) and Atkinson and Shiffrin's (1968) accounts, working memory is a temporary site in which information drawn from different sources is worked with dynamically, and that, in occupational therapy terms, it supports occupational performance.

Atkinson and Shiffrin's (1968) account of memory was questioned from different perspectives. First, Craik and Lockhart (1972) challenged their model of sequential structured memory stores. As already discussed, these authors questioned the evidence for discrete memory storage sites and suggested that Atkinson and Shiffrin's (1968) emphasis on 'control processes' indicated that the multistore approach was not sufficient, in itself, to explain the mechanisms involved (Craik and Lockhart 1972, p. 673). Craik and Lockhart (1972, p. 671) argued instead that research should focus on the 'levels of processing' involved in remembering.

Shallice and Warrington (1970) also questioned the assumptions of Atkinson and Shiffrin's (1968) model, based on neuropsychological evidence from studies with a neurological patient, K.F. K.F. had severely impaired short-term memory, which was evidenced by reduced ability to remember lists of words (Shallice and Warrington 1970). However, in one test it was found that K.F.'s impaired performance was consistent with a pattern normally observed when performing *long-term* memory tasks, suggesting that he was relying on long-term memory processes (Shallice and Warrington 1970). In addition, earlier work had shown that K.F.'s long-term memory performance appeared to be unaffected (Shallice and Warrington 1970).

These results indicated that the Atkinson and Shiffrin (1968) model, in which information was copied sequentially from the short-term store to the long-term store, was problematic, as K.F. performed normally on tasks requiring long-term memory while having severely impaired short-term capacity. Shallice and Warrington (1970) proposed instead a model for processing auditory–verbal information in which the inputs to the short-term store arrived in parallel, rather than serially. In this model, the short-term store processed information about the *sound* of words, or phonemics, while the long-term store simultaneously processed semantic information, related to the *meaning* of words (Shallice and Warrington 1970).

The Multicomponent Model of Working Memory

Stemming from these criticisms of Atkinson and Shiffrin's (1968) model, Baddeley and Hitch focused on the role of short-term memory as a putative working memory system (Baddeley 2015b; Baddeley and Hitch 2017). The participants in their early research were asked to perform digit span tasks, involving memorising strings of digits, at the same time as other tasks considered to be underpinned by working memory (Baddeley 2007; Baddeley and Hitch 2017). They found that digit spans of three items had very little impact on the other tasks, while spans of six digits were associated with marked performance impairment, for example with greater time needed to complete verbal reasoning activities (Baddeley and Hitch 2017). They proposed, therefore, that working memory might consist of a 'phonemic buffer' that stored and rehearsed 'speechlike' items, such as digits, relatively autonomously, and a more flexible 'central executive' that only became involved once the capacity of this buffer was breached, in this case when the number of digits in the string increased (Baddeley and Hitch 2017, pp. 68, 69). They also cited evidence showing that visuo-motor tasks disrupted the capacity to recall visually presented items, but had no effect on recall of the items presented phonemically, suggesting that there was a separate storage area for visual information (Baddeley and Hitch 2017). The researchers argued that their proposed model could account for Shallice and Warrington's (1970) findings about K.F. It could be that his phonemic buffer was impaired, while his central executive remained functional, allowing him to complete the task successfully (Baddeley and Hitch 2017).

The working memory scheme outlined by Baddeley and Hitch (2017) was developed and became known as the 'multicomponent model' (Baddeley 2007, p. 7). This model 'assumes that a range of subsystems may be brought to bear upon the performance of any task' (Baddeley 2007, p. 78). The original model comprised three components: the 'phonological loop', the 'visuospatial sketchpad' and the 'central executive' (Baddeley 2003, p. 830). For occupational therapists interested in analysing the memory processes involved in a specific occupational performance event, for example when a person with memory impairment visits the shops, it is important to grasp these components and also more recent additions to the model. These are explored in the following paragraphs.

The 'phonological loop' functioned with language and sound, storing spoken and acoustic information (Baddeley 2003, p. 830). The phonological loop concept explained why, for example, it was harder to remember a list of multisyllabic words when compared with shorter words (Baddeley 2000). It also accounted for findings that it is harder to remember a short list of similar-sounding letters, such as T and V, when compared with dissimilar ones such as S and K (Baddeley 2000). The phonological loop was considered to interact with language, indicating that more 'fluid systems' interact with the 'crystallized systems', such as language, embedded in long-term memory (Baddeley 2015b).

The phonological loop could be divided into two components, a storage site and a control process, based on articulation of information using 'vocal or subvocal rehearsal' (Baddeley et al. 2001; Baddeley 2012, p. 5). It has been estimated that items in the phonological store decay after around two

seconds, but that this rehearsal process can 'refresh' them, as long as all items are rehearsed within this time period (Gathercole and Hitch 1993). It is important to take these factors into account when presenting task instructions to a person with memory impairment, if the therapist is relying on written or spoken language.

The 'visuospatial sketchpad' was a restricted-capacity store for visual and spatial and, possibly, kinaesthetic information (Baddeley 2000, 2003, 2007). According to the model, aspects such as colour, location and shape are placed in separate silos, but are bound together by attention (Baddeley 2003). The visuospatial sketchpad was considered to interact with visual semantics, stored in long-term memory, another example of a more 'fluid' system interacting with a 'crystallized' memory system in long-term memory (Baddeley 2015b). The visuospatial sketchpad could also be divided into a region for storage, the 'visual cache', and an area in which information is retrieved in a dynamic manner, the 'inner scribe' (Baddeley 2003, p. 834). Again, the therapist should be aware of these factors; for example, the person with impairments in the visuospatial sketchpad may have difficulty remembering the location of items during a hospital-based kitchen task.

The 'central executive' was a controller that comprised two processes. The first was a process based on habits and guided by environmental cues; this was relatively automatic and therefore did not necessitate much attention (Baddeley 2003, p. 835). It may be noted that this is very similar to Kielhofner's (2008) description of 'habituation' and also Yerxa's (2000) comments about the energy-conserving aspects of 'habits' in occupational performance. Habit formation has been associated with the cerebral basal nuclei, which are discussed in detail in Box 1.3 later in the chapter. Second, a process called the 'supervisory attentional system', with restricted attentional capacity, could intervene to choose a course of action or identify solutions in situations where pre-existing habits were inadequate (Baddeley 2003, p. 835; Baddeley 2007). The central executive could also be involved in focusing on a task, shifting attention to another task or splitting attention between concurrent tasks (Baddeley 2003, 2015b). In addition, the supervisory attentional system is important in divided attention tasks, which are challenging for people with ATD (Baddeley 2015b). It has been found, for example, that people with ATD deteriorated in performance of concurrent tasks over a 12-month period, indicating that performance was linked to the disease progress (Baddeley et al. 2001).

At the start of the new millennium, a further temporary store with restricted capacity, the 'episodic buffer', was added to the multicomponent model of working memory (Baddeley 2000, p. 421; Baddeley 2003). The episodic buffer integrates information coded in multiple ways using a 'multidimensional code', which might include verbal, visual and semantic items that are drawn from various sources, which could encompass working memory itself, but also long-term memory and perception (Baddeley 2000, p. 421; Baddeley 2015b). The buffer acts as a 'workspace' in which this varied information can be bound together into a coherent episode that may be accessed consciously by the central executive (Baddeley 2000, 2003, 2015b). For example, it could facilitate the binding of different items of visual information into

an integral percept or the placement of words into meaningful 'chunks' that permit sentences to be understood (Baddeley 2003, 2015b, p. 82). In addition, the central executive can attend to specific items in the buffer and construct novel representations with the information, which is thought to assist in solving problems (Baddeley 2000). These ideas are applied in more detail in Chapter 5.

The different components of the working memory model have been associated with functions of particular regions of the brain. These are discussed in more detail in Box 1.2.

As mentioned already, it has been suggested that working memory may also hold information about kinaesthesis, a term that refers to sensations of movement (Bastian 1887; Schmidt and Lee 2005). In addition, it will be recalled that, according to Baddeley (2012), verbal information may be rehearsed vocally or subvocally within the phonological loop. Jaroslawska et al. (2018) presented experimental data that seems to confirm both that working memory has a kinaesthetic component and that it might deploy similar rehearsal, albeit tapping motor control mechanisms.

These researchers note that people given a sequence of motor commands execute the actions more accurately than they can repeat them verbally (Jaroslawska et al. 2018). They conducted three experiments in each of which 16 young adults performed a sequence of fine or gross motor tasks. In the first, participants executed a series of actions on objects of different colours. The tasks were increasingly complex and delivered via spoken instruction. In addition, there were three interference conditions: suppression of articulatory rehearsal; counting backwards; and simultaneous performance of a sequence of hand movements, designed to suppress motor rehearsal (Jaroslawska et al. 2018). The authors measured the number of actions performed accurately with the required objects (Jaroslawska et al. 2018).

They found that performance of recalled sequences was better than recall of the verbal instructions, but that *all* of the suppression activities resulted in impaired recall, although this was less marked in the motor recall condition. Their second experiment used the same design but with a series of gross upper-limb movements as the motor suppression task (Jaroslawska et al. 2018). They found that backwards counting and motor suppression were linked to impaired performance in all of the recall tasks (Jaroslawska et al. 2018). Experiment three involved repeat measures of three suppression conditions: no suppression, articulatory and motor. There were also two formats for recall: verbal and action (Jaroslawska et al. 2018). The authors found that there was significantly better recall for the action format, but that there were no differences between the action and verbal formats in the motor suppression condition (Jaroslawska et al. 2018).

Overall, Jaroslawska et al. (2018, p. 2446) propose that the 'action advantage' might be a result of short-term storage of 'kinaesthetic representations' of movements to be performed and that working memory may utilise cognitive systems mediating motor control. They propose that these findings may need to be incorporated into the multicomponent model of working memory (Jaroslawska et al. 2018). These insights seem to justify occupational therapists' focus on assessing memory via performance of purposeful activities, rather

than reliance on evaluations based on language and visual images, as is the case in many standardised cognitive screening tools, which fail to assess the kinaesthetic aspect of working memory.

Prospective Memory

Memory has also been subdivided into 'retrospective memory', for items from the past, and 'prospective memory', which involves making plans or commitments, retaining them while performing 'ongoing activities' and executing them at an appropriate time or on a particular cue (Eysenck 2015, p. 362; Graf 2012, p. 8). Prospective memory has been linked to activity in specific brain regions that are outlined in Box 1.2. Occupational therapists are involved in the assessment and treatment of people with memory impairments that may affect everyday commitments, such as remembering to take medication or attend appointments, and this memory system is therefore of great significance.

Zogg et al. 2012 have outlined a five-stage conceptual model of prospective memory. First, an intention is formed, along with a particular cue. The cue could be an event, for example encountering a specific person, or a predetermined time. This cue will trigger the retrieval of the intention. Prospective memory is improved if cues are processed in a manner relevant to the plan, because this association supports retrieval. For example, a medicine bottle placed on the table may be a more effective reminder than a note to take medication (Dismukes 2010; Graf 2012). Second, there is a delay, which could last up to a number of weeks, during which other activities are performed and the intention–cue dyad is in abeyance, although there may be ongoing monitoring for occurrence of the cue (Zogg et al. 2012). Third, there is cue recognition and self-retrieval of the intention (Einstein and McDaniel 2005; Zogg et al. 2012). Fourth, the intention is recollected from prospective memory. Fifth, the intention is executed (Zogg et al. 2012). These concepts may be useful in guiding occupational therapists when assisting people in identify cueing strategies for remembering commitments at an appropriate time.

Prospective memory can be divided into episodic and habitual subtypes: episodic prospective memory involves remembering to execute one-off intentions, while habitual prospective memory concerns tasks that must be performed repeatedly, such as taking prescribed medication (Graf 2012). In addition, prospective memory may be involved when remembering to resume a task that has been interrupted, and remembering to switch attention between tasks (Dismukes 2010).

Impaired prospective memory can lead to errors in everyday life with potentially serious consequences, for example neglecting to switch off an oven at the required time, and lapses in prospective memory have even been implicated in aviation accidents (Dismukes 2010). A close relationship has also been established between prospective memory capacity, as measured in laboratory tests, and medication adherence in people with human immunodeficiency virus and those with diabetes (Zogg et al. 2012). So, prospective memory impairments are potentially hazardous and should be considered during occupational therapy assessment.

BOX 1.2 LOBES OF THE CEREBRUM

The brain is divided into two cerebral hemispheres. The outermost part is the cerebral cortex. The largest and, in evolutionary terms, most recent part is called the neocortex, while the archicortex and paleocortex are older (Crossman et al. 2020). The surface of the neocortex is marked by folds called gyri, or gyrus in the singular, with grooves between them. The deepest grooves are termed fissures and the shallower ones are called sulci, or sulcus in the singular (Tortora and Derrickson 2011).

Each cerebral hemisphere is subdivided into four lobes with specialist functions. There are also a number of association areas, which are concerned with interpreting incoming sensory information and formulating appropriate motor responses (Martini 2018).

The lobes and key regions of the cerebral hemispheres are shown in Figure 1.2.

The frontal lobe is anterior to the central sulcus (Tortora and Derrickson 2011). This contains the primary motor cortex and premotor cortex, which are involved in motor control. Anterior to these is the extensive prefrontal cortex. This communicates with the parietal, occipital and temporal cortices (discussed later) via white-matter tracts called association fibres (Crossman et al. 2020; Tortora and Derrickson 2011). The prefrontal cortex is involved with high-level cognitive activity, including judgement, intellect, prediction and planning, learning and recall (Crossman et al. 2020; Tortora and Derrickson 2011).

The frontal lobes play an important role in the multicomponent model of working memory and also in prospective memory. For example, storage in the phonological loop has been linked to left hemisphere Brodmann area (BA) 40, while rehearsal has been linked to left BA 44, also known as Broca's area, a region involved in the motor production of speech (Baddeley 2000, 2007; Tortora and Derrickson 2011). In addition, the central executive has been associated with activation in the frontal lobes, while the

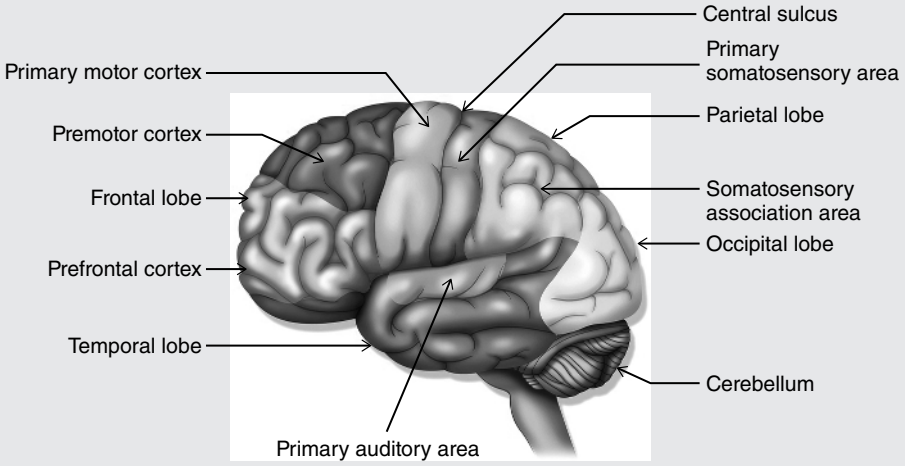


Figure 1.2 Lobes and key regions of the cerebral hemispheres (sagittal view of left hemisphere).

Source: RFBSIP/Adobe Stock.

right frontal lobe may be the neural substrate of the episodic buffer (Baddeley 2000, 2007; Berlingeri et al. 2008). Prospective memory, meanwhile, may depend on frontal brain regions as well as on the medial temporal lobes and the hippocampus (Zogg et al. 2012).

The parietal lobe is located posterior to the frontal lobe, superior to the temporal lobe and anterior to the occipital lobe. The parietal lobe contains the primary somatosensory area, which receives nerve impulses related to somatic sensations including touch, temperature, pain and proprioception, and allows conscious perception of these (Tortora and Derrickson 2011).

Posterior to the primary somatosensory area is the parietal association cortex, also called the somatosensory association area, which includes the inferior parietal lobule, an interface between the primary somatosensory area, the visual association areas of the occipital lobes, and auditory association area of the temporal lobes (Crossman et al. 2020; Tortora and Derrickson 2011). This area is involved in storage of somatic sensory memories and permits comparison of sensory inputs with experience from the past, allowing recognition of objects by touch (Tortora and Derrickson 2011).

The temporal lobes have a special role in declarative memory. The lateral aspect of the temporal lobe subdivides into superior, middle and inferior gyri (Crossman et al. 2020). The superior gyrus contains the primary auditory area, which is involved in the perception of sound (Crossman et al. 2020). Posterior to this is the auditory association cortex, where sounds are processed at a higher level, in the dominant, usually the left, hemisphere. This area includes Wernicke's area, which is involved in word recognition and the creation of thought from words (Crossman et al. 2020; Dronkers et al. 2000; Tortora and Derrickson 2011). There is minor variation in terminology and some authors state that Wernicke's area also spreads out to include part of the parietal cortex (Tortora and Derrickson 2011). As shown earlier, the inferior medial part of the temporal lobe is the location of the hippocampus, part of the archicortex, as well as the amygdala, and both of these structures are part of the limbic system, which is described further on (Crossman et al. 2020).

The inferior temporal cortex is considered as the region in which the highest level of processing of visual information takes place, allowing recognition of items on the basis of this visual input (Eichenbaum 2012). It is also thought to be the location of the silo in which long-term memories for visual items are stored (Eichenbaum 2012). This means that damage to this area can lead to 'visual agnosia', a failure to recognise visually presented items. Visual agnosia can be 'apperceptive', resulting from impaired perception, or 'associative', resulting from failure to recognise objects visually, despite having intact 'visual representations' (Eichenbaum 2012, p. 208; Gazzaniga et al. 2009, p. 226). A key message here is that cortical areas that are involved in analysing specific classes of information, in this case visual, are also involved in the long-term storage of that information (Eichenbaum 2012). For example, it has been shown that when people study a series of visual images and accompanying sounds, such as a picture of a dog with the sound of barking, and are subsequently asked to remember the appearance or sound of the object, visual regions and auditory regions were activated

according to the modality of the recollection (Eichenbaum 2012). This phenomenon depends on the capacity of cortical neurons and networks to reinitiate their standard sensory response patterns once the stimulus is unavailable, thereby facilitating representation in memory (Eichenbaum 2012). Eichenbaum comments:

> *memory should be conceived as intimately intertwined with information processing in the cortex, indeed so much so that memory and information processing are inherently indistinguishable . . . the mechanisms of the cerebral cortex involve a combination of information processing and memory to constitute neural networks that contain the structure of our knowledge about the world. (Eichenbaum 2012, p. 216)*

Furthermore, there is a degree of hemispheric specialisation. The right temporal lobe may be important when reconstruction of autobiographical items and when memory for events require visual imagery or imagery in other sensory modalities. The left temporal lobe may be important in the storing of distant semantic or word-based material (Kopelman 2002).

The occipital lobe contains the primary visual cortex, which is where nerve impulses related to vision are first perceived (Crossman et al. 2020). The occipital lobe also contains the visual association cortices, which are engaged in recognition and interpretation of visual stimuli (Crossman et al. 2020). In the multicomponent working memory model, the visuospatial sketchpad is thought to depend on right hemisphere regions, including the temporoparietal lobe (BA 40) and the right occipital lobe (BA 19) (Baddeley 2000; Baddeley 2007).

To continue the examination of the structure of the brain, Box 1.3 explores the basal nuclei and Box 1.4 describes the limbic system.

BOX 1.3 THE BASAL NUCLEI

The basal nuclei is a group of three paired nuclei named the caudate nucleus, putamen and globus pallidus, which are located deep to the cerebral cortex (Crossman et al. 2020). The caudate nucleus and putamen are often labelled collectively as the striatum or neostriatum; the putamen and globus pallidus are also sometimes described collectively as the lentiform nucleus (Crossman et al. 2020). Again, there is some variation in terminology and two other nuclei, the subthalamic and substantia nigra, are sometimes included within the basal nuclei (Crossman et al. 2020). In addition, the basal nuclei are often referred to in clinical practice as the basal ganglia, although, because a ganglion is a group of nerve cells located in the peripheral nervous system and a nucleus is located in the central nervous system, basal nuclei is a more anatomically correct term (Tortora and Derrickson 2011).

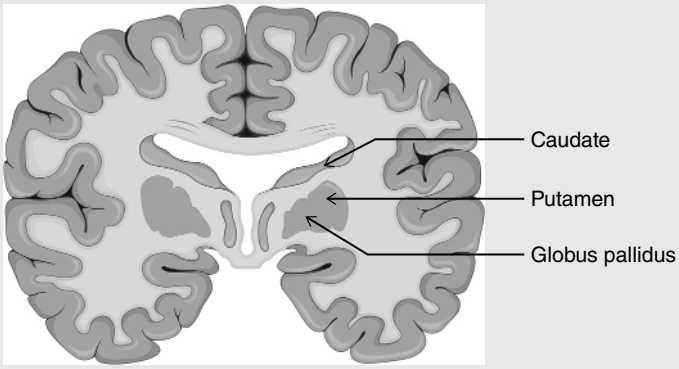


Figure 1.3 Basal nuclei (anterior coronal view of cerebrum).
Source: Design Praxis/Adobe Stock.

The component parts of the basal nuclei are shown in Figure 1.3.

The basal nuclei are considered to be involved in initiation of movements and behaviours needed in specific situations, and also inhibition of inappropriate actions (Crossman et al. 2020). The basal nuclei are known to be involved in learned behavioural responses to 'antecedent stimuli'; an example would be switching on a light switch in response to entering a darkened room (Yin and Knowlton 2006, p. 464). They are involved in the formation of habits and have a role in 'instrumental behaviours', which are actions required to produce a specific response (Yin and Knowlton 2006, p. 464). Crucially, these learned repertoires depend on the memory of the value placed on the desired response and also awareness of the relationship between the action and the outcome (Yin and Knowlton 2006).

The basal nuclei, specifically the dorsal region of the striatum, are involved in non-declarative procedural learning (Yin and Knowlton 2006). Yin and Knowlton (2006), for example, show that patients with Parkinson's disease, which affects the basal nuclei, are able to learn a task involving prediction of an outcome when presented with a stimulus that involves learning the linkage between the stimulus and the outcome, performing as well as without neurological impairment do. However, the evidence suggests that people with Parkinson's disease rely for this on medial temporal lobe mechanisms, which are involved in declarative memory, while individuals without neurological impairment are able to learn the task using the basal nuclei (Yin and Knowlton 2006). In addition, people with Huntington's disease, which also affects the basal nuclei, have been shown to be impaired on tasks involving procedural learning of motor skills (Eichenbaum 2012). Yin and Knowlton (2006) comment that it is likely that most learning involves a combination of habitual and declarative mechanisms, and that the relative contributions of these memory systems may be a function of the quantity of training involved, the difficulty of the learned associations involved and the integrity of the basal nuclei and medial temporal lobes. Indeed, they maintain that behaviour is likely a result of basal nuclei–cortical interaction, rather than a product of either region alone (Yin and Knowlton 2006).

It has also been found that when learning a new motor skill, the caudate nucleus and prefrontal cortex, labelled the 'associate network', are active.

However, once the skill is learned thoroughly and becomes more habitual, then the activation pattern during performance changes to the putamen and motor cortices, described as the 'sensorimotor network' (Yin and Knowlton 2006, p. 472). In addition, there are stronger connections between higher-order association areas of the prefrontal cortex with the caudate, and stronger connections between more dorsal motor regions of the cortex and the putamen (Crossman et al. 2020). One final point here is that another subcortical structure, the cerebellum (shown in Figure 1.2), is involved in the fine-tuning of learned motor responses in procedural memory (Eichenbaum 2012).

BOX 1.4 THE LIMBIC SYSTEM

The limbic system is a very ancient part of the cerebrum, located in the rim on the medial aspect of the cerebral hemisphere, from which it derives its name ('limbus' means rim in Latin) (Gazzaniga et al. 2009; Crossman et al. 2020). An earlier conception of the existence of a specific emotional system in the brain was proposed by James Papez in 1937, and the system has therefore also been known as the 'Papez circuit' (Eichenbaum 2012; Zogg et al. 2012). Papez included the cingulate cortex, the hippocampal region, the mammillary bodies of the hypothalamus and the thalamic nuclei (Eichenbaum 2012). A more contemporary view of the limbic system includes extra areas in addition to those proposed by Papez: the amygdala, septum and prefrontal cortex (Eichenbaum 2012).

The components of the limbic system are shown in Figure 1.4.

It is important to stress that there is some disagreement about the precise components of the limbic system and even whether the title is still valid (Eichenbaum 2012; Gazzaniga et al. 2009). However, authors generally include the parahippocampal gyrus and hippocampus, already discussed (Tortora and Derrickson 2011). In addition, it includes the amygdala,

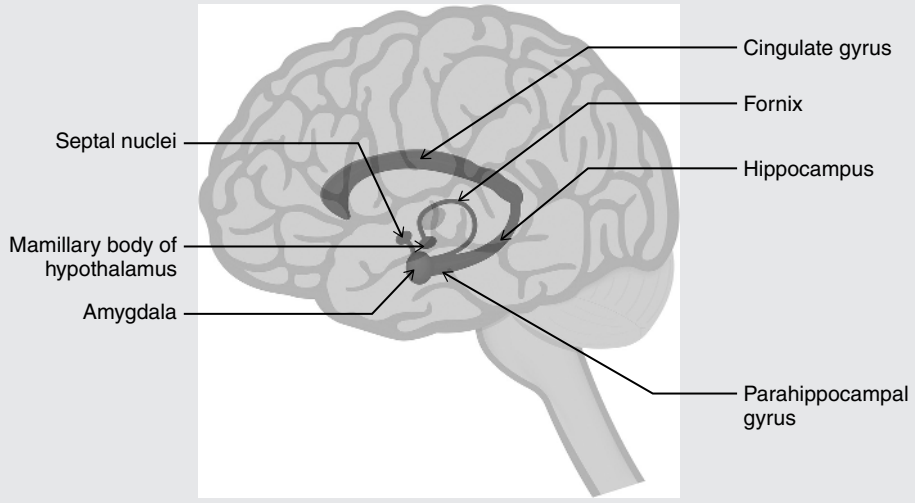


Figure 1.4 The limbic system (left sagittal view).
Source: joshya/Adobe Stock.

which has connections with the inferior temporal association area, the thalamus, olfactory tract and septum (Crossman et al. 2020). Furthermore, the amygdala receives inputs, via the thalamus, from visceral organs (Eichenbaum 2012). Overall, the amygdala receives and integrates information from multiple modalities (Eichenbaum 2012).

The limbic system permits fast responses to potential danger, so that sensory information passes by the neocortex and transmits directly to the limbic system, and relatively automated behaviours, such as fight or flight, are then initiated via the basal nuclei (Crossman et al. 2020). This is sometimes called a 'low road' for information processing, which allows 'quick but dirty' communication of sensory information from the thalamus to the amygdala, allowing for a rapid response (Gazzaniga et al. 2009, p. 372). Opposed to this is the 'high road', via which sensory inputs from the thalamus are first processed at the cortical level, before relay to the amygdala (Gazzaniga et al. 2009, p. 372). It will be shown later in this book that disorders in this area may underpin the problems encountered by people living with post-traumatic stress disorder (Brewin 2001).

The learning and memory of emotional responses underpinned by the amygdala may be implicit, non-declarative learning, meaning that the person does not have conscious awareness of the learning (Gazzaniga et al. 2009). Alternatively, the learning and memory can be explicit and declarative; here, the amygdala may work with the hippocampus to give a memory emotional salience, enhancing the force of the memory by its effect on storage (Gazzaniga et al. 2009). At the same time, explicit learning, perhaps about the dangers involved in a particular action and based on the hippocampus, may activate the amygdala so that, in future contemplation of this action, there will be generation of a fear response, reinforcing the message that it could bring unwelcome consequences (Gazzaniga et al. 2009).

Some evidence for the role of the amygdala comes from the studies of Henry Molaison, who had the amygdala removed bilaterally during surgery (Eichenbaum 2012). He showed lack of awareness of satiety and would continue eating even when he had just had a meal, blunted awareness of pain and a lack of interest in sex, despite being aware of sexuality at a declarative level (Corkin 2013; Eichenbaum 2012).

Other limbic system nuclei include the septum that communicates with the habenular nucleus of the epithalamus; this latter nucleus is involved in linking emotional responses and remembered aromas (Crossman et al. 2020; Tortora and Derrickson 2011). The orbitofrontal cortex is part of the frontal lobe and also has strong connections to the limbic system. For example, the orbitofrontal cortex connects to the inferior temporal cortex by means of the uncinate fasciculus, which will be discussed in relation to memory later in the book (Crossman et al. 2020). Fronto-temporal dementia, also discussed later in the book, involves atrophy in the prefrontal cortex and the amygdala (Crossman et al. 2020).

The limbic system communicates extensively with the association areas of the neocortex, meaning that goal-focused actions can be linked to more instinctual behaviour and homeostatic mechanisms, imbuing memory with these primitive characteristics (Crossman et al. 2020). Crossman et al.

(2020) provide an account in which sensory information is first detected in a specific modality, for example via vision or audition, and is then processed at higher levels in the parieto-occipital association areas, followed by the frontal and inferior temporal association cortices, until it achieves independence from sensory modality and can be processed in a semantic manner. The information then enters the limbic system via an indirect route to the hippocampal formation, which was discussed in Box 1.1, or directly to the amygdala (Crossman et al. 2020). Purposeful actions depend on the learned associations between past actions and outcomes, including emotional responses to rewards and sanctions, and in that sense depend on the memory properties of the limbic system (Crossman et al. 2020).

Towards a Culturally Situated Understanding of Memory

A school of psychology developed in the Soviet Union in the 1930s that stressed that cognitive processes change with social and historical development (Luria 1976). In addition, consciousness was not a passive property of the individual mind, but was shaped by the ways in which humans reacted to and acted on their environment in specific social and historical contexts (Luria 1976). The child's mental processes, for example, are shaped by those of previous generations via language, tools and the products of social labour (Luria 1976). Luria (1976, p. 164), stated:

> *The basic categories of human mental life can be understood as products of social history – they are subject to change when the basic forms of social practice are altered and thus are social in nature. (Luria 1976, p. 164)*

Luria (1976) worked with Vygotsky to analyse the mental operations of people living in Uzbekistan and Kirghizia during the social and economic changes resulting from the Russian Revolution of 1917. Key here were changed working practices, moving from small village life and high levels of illiteracy to collective agricultural and industrial production (Luria 1976). According to Luria (1976, p. 15), an important shift was that from 'graphical-functional' activity, in which cognition was orientated towards the objects of labour, to mediated thought, distinguished by higher levels of abstraction, with the emergence of thought guided not just by the practical task in hand but by language and logic.

For these thinkers, memory in non-literate societies was predominantly 'natural memory', influenced by the perception of external stimuli; however, the use of memory aids and the emergence of writing meant that memory became more 'culturally-elaborated' (Vygotsky and Cole 1978). At this stage, memory incorporates stimuli generated by the person themselves, described as 'signs' (Vygotsky and Cole 1978, p. 39).

Vygotsky and Cole (1978) believed this to be a feature of individual development as well. Vygotsky's research group found in experiments that

children aged 5 or 6 could not use stimulus cards to help them in a memory task, but that children between the ages of 8 and 13 were able to do so. Vygotsky and Cole (1978) argued that tool use and language, which are both cultural phenomena and both emerge in infancy, provide the basis for further psychological development. Throughout development, they argued, there is then an interaction between biological processes and more complex psychological processes, which are of 'sociocultural origin' (Vygotsky and Cole 1978, p. 46). The young child at 5 or 6 was unable to use external signs to support memory, but at a later stage signs could be used to aid memory retrieval (Vygotsky and Cole 1978). Where aids were used at the younger age, it was found that the child only made use of them when the sign had some direct representation of the item of to be recalled, so the sign was not being used as a *symbol* (Vygotsky and Cole 1978). They argued that memory in early childhood was the foundation of other psychological processes, so that thinking *is* remembering (Vygotsky and Cole 1978). For example, if asked to describe a snail the child will give a concrete description of the qualities of a snail that they have observed, based on memory, rather a description of the abstract concept (Vygotsky and Cole 1978). However, during adolescence, when logical concepts are internalised, 'to recall means to think' and recognition involves identifying the part of the concept that the 'task indicates has to be found' (Vygotsky and Cole 1978, p. 51). In particular, mature human memory makes use of signs, an exemplar of which is tying a knot in a handkerchief to remember something, so that remembering becomes an 'external activity' (Vygotsky and Cole 1978, p. 51).

Conclusion

This chapter has surveyed the evidence linking learning and memory to experience-dependent neural plasticity. The potential role of long-term potentiation as a mechanism underpinning memory formation was discussed. It was shown how, remarkably, this phenomenon, which was identified in the 1970s, seemed to confirm the predictions of Hebb's postulate about learning and memory originally put forward in the 1940s.

There was a brief discussion of the history of thinking on memory. It was shown that the shift from behaviourism to an information processing approach, the so-called 'cognitive revolution' in the United States, opened up new vistas in memory research. At the same time, there were other traditions of thinking on memory, for example that represented by Bartlett in Britain and Luria and Vygotsky in the Soviet Union.

It was shown how a person's occupational history can influence neural plasticity and, in particular, brain regions know to be involved in memory. This should be a concern for practitioners guided by occupational justice principles. These issues are discussed further in Chapter 2.

The case of Henry Molaison was discussed in some detail. The space given to this history is justified by this case's lasting contributions to memory theory, in particular the understanding of the role of the medial temporal lobes and the hippocampal memory system. In addition, the categorisation of memory domains into non-declarative and declarative, or procedural and semantic, owes much to the research that was done with Molaison. Again, it may be

useful to pause for thought here: it is hard to think of another example of a single case generating so many widely accepted and influential theories.

A detailed historical account of some contemporary concepts of memory was given. These included Tulving's tripartite hierarchy of procedural, semantic and episodic memory. Also there was discussion of the multicomponent model of working memory. One advantage of the latter model is that it acknowledges a central role for attention, in the form of the central executive. In addition, it is concerned with goal-directed task performance, and therefore has relevance for occupational therapists.

It was shown how these concepts can be applied to typical assessment situations in which the occupational therapist may be involved with persons with memory impairment. Furthermore, there was an explanation of concepts of prospective memory, with examples of application to occupational performance.

An outline of the structure and functions of key cerebral regions in relation to memory performance was provided. In particular, there was a detailed description of the hippocampal region, which is especially relevant to discussions of memory.

Finally, there was a brief overview of the socio-historical school of psychology. It is hoped that overall, occupational therapists may be encouraged to look beyond the, undoubtedly seminal, work undertaken in North America and consider other traditions of thinking on memory and cognition in general. These may be less well known, but they fit well with aspects of occupational therapy theory.

Points for Discussion

1. Steve is a senior occupational therapist on an acute stroke unit. He is training newly qualified therapists to use an electric whole-body hoist. Explain how he can use chunking to support the trainees to remember how to complete this task.
2. Maryam is a patient who has memory impairments following a TBI. She reports difficulty remembering to pick up her children from nursery each day. In addition, she states that she forgot a one-off meet-up with an old friend. Which memory systems would underpin these errors? Also, state some appropriate cues that might help Maryam.
3. Charles has ATD and impaired episodic memory. What suggestions could the occupational therapist make to his family to support retrieval of episodic memories?

Activities

1. Chunk the tasks involved in the activities of washing and dressing.
2. Chunk the tasks involved in completing grocery shopping.
3. Use the concept of 'depth of processing' when presenting a complex kitchen task to a service user with memory impairment.
4. Reflect on a critical incident using Gibbs' Reflective Cycle; discuss how episodic memory supports this process.

5. See if you can remember this sequence of random numbers:

   996297

   682701

   788688

   177753

   884523

   961890

   Now construct an array of numbers that is made up of the dates of birth of people close to you and telephone numbers that you know. What do you notice about how many you can remember in comparison with the random numbers? Can you explain any differences you notice?

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