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ESSENTIALS OF HUMAN MEMORY

Alan Baddeley

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This Classic Edition of the best-selling textbook offers an in-depth overview of approaches to the study of memory. With empirical research from both the real world and the neuropsychological clinic, the book explains the fundamental workings of human memory in a clear and accessible style. This edition contains a new introduction and concluding chapter in which the author reflects on how the book is organized, and also on how the field of memory has developed since it was first published.

Essentials of Human Memory evolved from a belief that, although the amount we know about memory has increased enormously in recent years, it is still possible to explain it in a way that would be fully understood by the general reader.

After a broad overview of approaches to the study of memory, short-term and working memory are discussed, followed by learning, the role of organizing in remembering and factors influencing forgetting, including emotional variables and claims for the role of repression in what has become known as the false memory syndrome. The way in which knowledge of the world is stored is discussed next, followed by an account of the processes underlying retrieval, and their application to the practical issues of eyewitness testimony. The breakdown of memory in the amnesic syndrome is discussed next, followed by discussion of the way in which memory develops in children, and declines in the elderly. After a section concerned with mnemonic techniques and memory improvement, the book ends with an overview of recent developments in the field of human memory.

Written by the leading expert in human memory, recently awarded the British Psychological Society Research Board Lifetime Achievement Award, *Essentials of Human Memory* will be of interest to students of Cognitive Psychology, Neuropsychology, and anyone with an interest in the workings of memory.

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Classic Edition

Alan Baddeley

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PREFACE

What are the essentials?

Research scientists are, quite rightly, typically concerned with the problem of the moment, 'what's hot', and how can the most recent research tell us where the next breakthrough might come? There is danger that when this is transferred to teaching, too much emphasis is placed on current interests and fashions, and too little on the fundamentals. I myself critically made this mistake when asked if I would be happy to support a new edition of *Essentials of Human Memory*, remembering its origins many years ago and the huge amount of memory research that has been carried out since that time. Have the essentials remained the same?

The book has gone through a number of revisions but at heart it is based on a book written in 1982, aimed at the general reader and entitled *Your Memory: A User's Guide*. It had, for me at least, a rather unusual origin. I was at the time Director of the Medical Research Council Applied Psychology Unit in Cambridge, which comprised around 100 people focused on linking theoretical psychology with its practical application. I was also giving a lecture course on memory at Cambridge University, and when invited to write a short popular book on memory decided it would be an interesting challenge. I was able to take a month away from my regular duties during a summer break; I tend to write by dictating and planned a month of walking and talking through the Norfolk countryside, a method of writing I can strongly recommend, particularly if there is a village pub at the end. Alas, I developed an acute back problem and was unable to walk. Could I still write? I decided to try, sitting on the edge of a bed looking out at the window over the fields, surrounding myself with a few books and notes and trying to describe for a general reader what we knew about memory and why I myself found it fascinating. To my relief I found that I could

work this way, and, to my surprise, I produced a first draft within the month, a rate of writing I have never managed before or since; five years is more typical for most of my books.

What I tried to do was take the fundamentals of my lecture course and present them in a way that would be accessible and interesting to a general reader, using examples from everyday life and personal anecdotes where appropriate. A part of the contract was to include a large number of photographs, half of them in colour, exactly the opposite to the case with a scientific paper where photographs were discouraged unless absolutely essential. The reason for this was that I was producing what was known as a 'packaged' book which would have high production values, the cost of which would be recovered by selling it widely across an international market. I was given a pile of possible candidate pictures, and asked to fit them it, with suitable captions. After an initial shock, I rather enjoyed this challenge, having realised that the purpose of the pictures was not to be subservient to the text, but to provide a parallel and attractive format that could intrigue and tempt a prospective reader.

The book proved a success, being published in many languages and attracting a wide range of readers ranging from the elderly, concerned at their declining memory, to teenagers and people wondering whether to study psychology or not. The *User's Guide* has remained in print ever since. I was also pleased to learn that some of my colleagues were using it as a basic memory text, but were finding it hard to obtain in the US. For that reason, Psychology Press bought the rights to use it as the foundation of a new version, specifically designed as a textbook, resulting in the publication of *Essentials of Human Memory*.

But what are 'the essentials', and have they not changed dramatically since my Cambridge lectures? We certainly know a great deal more about memory than we did; the bulk of the references in my most recent advanced memory text (Baddeley, Eysenck, & Anderson, 2009) were published after the appearance of the *User's Guide*. However, these were virtually all built on the foundations that already existed in the 1980s, indeed the chapter headings from our recent advanced text are virtually identical to those featuring in the *User's Guide*. Of course that could simply mean that I am set in my ways. If so the ways seem to be rather generally accepted given that virtually all of nine referees from three different countries who were asked to comment on our 2009 text prior to possible revision felt that the structure was appropriate.

This suggests that the psychology of memory has reached a point of some stability in its broad theoretical basis, and also, I would suggest, in its application to everyday life. This is a comparatively new situation. Before the 1960s, there were no generally accepted memory textbooks. There were important individual books presenting a particular viewpoint on memory starting of course with that of Ebbinghaus (1885), the first person to apply the scientific method to the study of memory, going on through Bartlett's (1932) case for a stronger link with everyday life and the plea by Katona (1940) for consideration of the active organising role of the rememberer. A closer approximation to a text was McGeoch

and Irion's (1952) summary of the stimulus–response approach to human learning and memory, an approach sometimes referred to as *verbal learning*.

All of these made important contributions to the psychology of memory but suffered from a narrowness of focus that has made such approaches hard to generalise across the memory domain.

The potential for broader generalisation increased during the 1960s with the onset of what has become known as the *cognitive revolution*. This was a broadly based development that was strongly influenced by the computer and by the information processing metaphor, encouraging a much wider range of theorising than was possible using earlier approaches. Theoretical developments ranged from precise attempts to produce a detailed model of specific aspects of behaviour through to broad theoretical frameworks. This did not mean that people all agreed with each other, but the cognitive approach did provide a way of thinking about a range of topics within the domain of human memory that extended beyond previous theories, encouraging at the same time the development of new methods and concepts. The first memory text within this broad framework was produced by Jack Adams (1967) whose background had been in motor skills. This was followed some nine years later by two much more substantial texts. One was by Robert Crowder (1976) who came from a relatively classic verbal learning background, and the second by me (Baddeley, 1976) from a more information processing perspective. I would argue that despite our somewhat different theoretical backgrounds, Crowder and I broadly agreed on the fundamentals, and that these have stood the test of time.

So what are the fundamentals? First of all, underpinning most of what follows in this book is the assumption that theories and concepts should be based on observable evidence. This may come both from the behaviour of people in tightly controlled experiments or from the observation of behaviour in more complex real world situations. In my view it also includes statements that people make about their experience of remembering, while bearing in mind that, although these may provide valuable hints, they may not be an accurate or reliable account of the processes underlying memory, many of which are almost certainly not available to conscious awareness. Importantly, all such evidence, regardless of origin, should be replicable; investigators should be able to repeat their findings, which should also be able to be replicated by others. This is of course true of science in general, so what is essential about memory?

The first thing to note is that memory is not a single unitary faculty, but rather represents a series of separable systems that perform different tasks over widely different time scales from fractions of a second to many years. Given their diversity, it is hardly surprising that these systems operate in different ways. In order to understand them, we have to find ways of separating them. Much of the controversy in the field has concerned the ways in which we do this. One way is to study patients who, as a result of brain damage, have a deficit to one such system. For example, densely amnesic patients have great difficulty in

acquiring new information and retaining it even over intervals of minutes, but may be perfectly able to hear and repeat back a telephone number. Other patients may show exactly the opposite pattern, suggesting that these two tasks depend on different aspects of memory, potentially based on separate memory systems.

Another method is to try to block one system and look at the impact on memory performance. For example, if we thought that the temporary storage system necessary for holding a telephone number was also important for learning more generally, then we might try to block that system, for example requiring the rememberer to hear and repeat a telephone number while reading a prose passage, then asking for memory for content of the passage. In fact, although there is a small cost, the verbal system responsible for briefly holding the telephone number is not essential for processing meaning and has little impact on prose memory, again suggesting separable systems (Baddeley & Hitch, 1974; Jefferies, Lambon-Ralph, & Baddeley, 2004). As you will see later, it proves to be the case that each of these two systems can itself be broken down into smaller components, all of which work together to enable us to process and remember what we have just experienced.

Other forms of learning are different again; acquiring a skill such as swimming or cycling operates in a rather different way; the learning process is more automatic, as is retrieval of the skill. You don't consciously remember how to swim or ride a bicycle, you simply get on a bike or plunge into the water and do it. These and other related systems are referred to as *implicit* because they do not require an explicit intentional conscious attempt to recall or recognise a previous experience.

In describing these various systems it is common to use the analogy of a *store* where information is held until it is needed. This should not be taken to mean that there is a specific location in the brain that serves as a warehouse for that particular type of information; it is much more likely that all kinds of information are stored across a number of brain locations. I myself find it useful to employ a unitary label for particular types of storage without making any strong assumptions about either the way which information is maintained or the underlying brain processes.

Any system that stores information, whether biological, like human memory, or structural, like a library or a computer hard disk, will have three basic requirements. It must first of all be able to register the information, a process known as *encoding*. Second, it must be able to maintain that information over time, the process of *storage*, and finally it must be able to find and output that information when required, the process of *retrieval*. In practice, these three interact with each other; things that you pay particular attention to are more likely to be stored, and hence retrieved subsequently. People asked to recall the contents of a recently viewed house recalled different things when cued to think of it as a potential purchaser from what is remembered when subsequently asked to recall from the viewpoint of a burglar. When the viewpoint changed, different

things were recalled; both groups had stored more than they initially retrieved (Anderson & Pichert, 1978).

Storage itself depends upon a series of biochemical processes that may become less efficient with aging and may be disrupted by factors ranging from a blow on the head to Alzheimer's Disease. What is not stored cannot be retrieved, but not everything that has been adequately encoded may be accessible at any one time. You probably have had the experience of knowing someone's name and having it on the tip of your tongue without being able to produce it. Giving you the first letter often does the trick, making it clear that the information had been stored, but was not retrievable at that particular time.

The complexity of memory means that in order to study it, it is often necessary to try to control the experimental situation in great detail if you are to achieve clear, meaningful results; this narrowness of focus can make the subject seem rather dry and abstract. Fortunately, it is still possible to take a broad view, as I did in both the *User's Guide* and *Essentials*, to describe the basic research relatively simply, and then to relate it to everyday memory experience. We know a great deal more about memory than we did when *Essentials* was first published. This has however mainly reflected a broadening and enrichment of our basic knowledge. The essentials are still essential.

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1

WHAT IS MEMORY?

'I have a terrible memory.' How often have you heard that? In my own case, whenever I meet someone, and in casual conversation admit that I carry out research on memory, by far the most common response is 'You should do some work on me—my memory is awful!' So is mine—I even managed to forget to turn up for a radio phone-in on memory. I was reminded of my dreadful lapse by reading the radio section of the newspaper, and arrived at the studio just in time to be asked by the anchor man for 'a few tips on improving your memory'!

I also believe, however, that I have a good memory, and would argue, despite its occasionally embarrassing fallibility, that both my memory and yours exceed that of the best computer in terms of capacity, flexibility, and durability. In the chapters that follow, I hope to persuade you to share my admiration.

Perhaps the best way to appreciate the importance of memory is to consider what it would be like to live without it, or rather without them, as memory is not a single organ like the heart or liver, but an alliance of systems that work together, allowing us to learn from the past and predict the future.

In recent years we have learned a great deal from the study of memory impairment following brain damage. Almost any damage to the brain will lead to some slowing in learning and some impairment in the speed with which we access old memories. Certain areas of the brain, however, are particularly crucial for memory. Serious damage to these can lead to dense amnesia, which can be a crippling handicap.

Consider the case of Clive Wearing, a talented musician and an expert on early music, who fell ill as a result of a viral infection (Wilson, Baddeley, & Kapur, 1995). The herpes simplex virus is carried by a large percentage of the population, typically having no worse effect than causing the occasional cold sore. On very rare occasions, however, the virus manages to overcome the brain's natural defences and cause an inflammation known as encephalitis. This can lead

to extensive brain damage, and until relatively recently was often fatal. Although the disease can now be treated, patients often suffer extensive brain damage, which frequently leads to memory problems.

Clive Wearing is a particularly dramatic example of the terrible after-effects of encephalitis. He is so impaired that he cannot remember what happened more than minutes before, with the result that he is convinced that he has only just recovered consciousness. He keeps a diary which records this obsession—page upon page of records indicating the date, the time, and the fact that consciousness has just been regained. When confronted with evidence of earlier apparent conscious awareness, by being shown a video of himself, for example, he becomes upset and denies the evidence, even after many years of being in this condition. It is as if, faced with the enormity of a life limited to a horizon of a few seconds, he clings to the view that he has just recovered consciousness, with the implication that in the future all will be well.

Clive's world was very effectively portrayed in a television programme by Dr Jonathan Miller entitled 'Prisoner of Consciousness'. Whenever his wife appears, Clive greets her with the joy appropriate to someone who has not seen a loved one for many months. She has only to leave the room for two or three minutes and return for the joy to be repeated, a process that is always full of emotion, and always expressed in the same way. Clive lives in a permanent present, unable to register change or to use the past to anticipate the future, a situation he once described as 'Hell on earth. It's like being dead—all the bloody time.'

Clive's memory for his past is less dramatically impaired than his ongoing memory. Nevertheless it is severely disrupted—he knows who he is, and can give you a broad outline of his earlier life, but with very little accurate detail. He is not certain, for instance, whether his current, second, wife and he were married or not. He can remember, given appropriate prompts, certain highlights of his life, such as singing for the Pope during a papal visit to London or directing the first performance of *Messiah* in London with authentic instruments and decor. He had written a book on the early composer Lassus, but can remember virtually nothing about him. His visual memory is also impaired—he spent four years in Cambridge, but does not recognise a photograph of his old college. His general knowledge is similarly reduced—he has no idea, for example, as to the author of *Romeo and Juliet*.

There is, however, one area that is remarkably preserved, namely his musical skills. On one occasion his wife returned home to discover that his old choir was visiting him, and that he was conducting them just as he did in the old days. He can sight-read music and is able to accompany himself on the harpsichord, playing quite complex pieces and singing with great skill and feeling. Alas, he appears to find the transition from music back to his desolate state of amnesia particularly disturbing, with the result that music does not seem to provide the kind of solace that one might have hoped.

Clive has been in this state since 1985. He is still convinced that he has just woken up. He still lives in a desolate, eternal present. He cannot enjoy books

because he cannot follow their plot, and takes no interest in current affairs because, likewise, they are meaningless as he does not remember their context. If he goes out, he immediately becomes lost. He is indeed a prisoner limited to a brief island of consciousness in the sea of amnesia.

The tragic case of Clive Wearing demonstrates that memory is important, but what *is* memory?

The physical basis of memory

It is often assumed by non-psychologists, and indeed by a few psychologists, that psychological theories should have the final aim of giving a physiological account of psychological facts. This view, which is sometimes called reductionism, sees a continuous chain of explanation extending down from psychology through physiology, biochemistry, and biophysics, to the subatomic particles studied by the physicist.

Suppose I were an architect and wanted to find out about London's St Paul's Cathedral. I could pursue my enquiries at many different levels. I could ask about the history of the building and how it came to be built following the Great Fire. I could ask about the style, and the influence of classical architecture on Sir Christopher Wren, who designed it. I could ask about its function, and I could ask about the details of the material that went into its construction. The viewpoint that a study of memory must begin with its biochemistry would be somewhat analogous to advocating that anyone interested in St Paul's Cathedral should begin by studying the atomic structure of brick and stone. There is no doubt that such a study would be relevant, and indeed if the atomic structure of the bricks had been inappropriate, the cathedral would never have remained standing. However, one could know everything about the atomic structure of brick and stone and yet know virtually nothing of interest about the cathedral. On the other hand, one could know a great deal about the cathedral without having any knowledge of the physio-chemical properties of brick and stone.

The structure of materials does of course at some point constrain the architect and obviously has an important bearing on the creation of a building. Similarly, in principle, a number of aspects of human memory could be importantly influenced by physiological or biochemical findings. However, many of the claims for an understanding of the molecular basis of memory that were being made a few years ago have since been shown to be premature—the neurochemistry of memory is proving much more complex than was previously suspected. There is no doubt that progress is being made in this important area, and that one day there may be a very fruitful collaboration between the human experimental psychologist and the neurochemist. At present, however, there is little area of overlap, so I will give only a brief account of some of the work concerned with the neurophysiology of learning and memory.

The neurophysiology of learning and memory

Learning almost certainly involves a chain of electrophysiological and neurochemical changes in the brain. Such changes are currently very difficult to study in the human brain, but considerable progress is being made in understanding the processes involved in learning in less complex organisms. For example, Eric Kandel has worked on the very simple marine organism *Aplysia*, which combines neuronal simplicity with a capacity for simple learning (Bailey & Kandel, 1995). It is capable, for example, of showing the phenomenon known as *habituation*. This is a process whereby a stimulus that initially evokes a response gradually comes to be ignored when it is repeated, in the absence of any positive or negative outcome. In the case of *Aplysia*, if one stimulates the siphon, both the siphon and the gill tend to be withdrawn initially; after repeated stimulation the withdrawal response stops, an effect that can last from minutes up to weeks. The withdrawal response involves electrical transmission across synapses, the special junctions between neurons, or nerve cells. Transmission across synapses depends on neurotransmitters, chemical messengers that allow one neuron to communicate with another. These in turn depend on the release of calcium ions. The process of repeated stimulation gradually reduces the activity of the channels that release calcium ions, thus reducing the likelihood that sufficient calcium ions will be released to cause firing or onward transmission of a nerve impulse.

The opposite to habituation is *sensitisation*, a process that occurs when an independent stimulus increases the probability of a response. Hearing a shot, for example, might make you sufficiently jumpy to be startled by the sound of a car door slamming subsequently. In the case of *Aplysia*, an unpleasant stimulus to the tail enhances the withdrawal response when the siphon is touched. This is caused by an increase in the amount of neurotransmitter substance released as a result of a greater influx of calcium ions into the terminal.

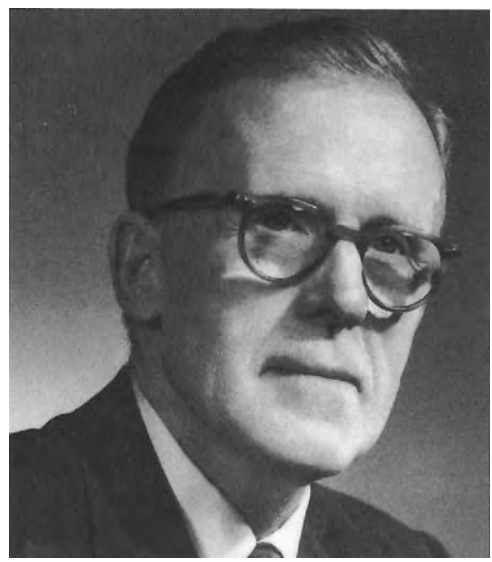
Aplysia is also capable of the form of learning known as *classical conditioning*. The best known example of classical conditioning is that previously observed in dogs by the Russian physiologist Pavlov, who showed that when the presentation of food was regularly associated with ringing a bell, eventually the sound of the bell alone led to salivation. In the case of *Aplysia*, the equivalent to food is a strong stimulation to the tail, which causes the automatic response of withdrawing the gill and siphon. The equivalent of the bell is a mild touch of the siphon, which does not of itself lead to withdrawal. However, when the light touch is consistently followed by a strong tail stimulus, it eventually leads to withdrawal of the gill and siphon in the absence of the tail stimulus. This simple analogue of learning can persist for several days. Kandel suggests that the underlying mechanism is similar to that of sensitisation; the light touch to the siphon eventually leads, through association with the stronger tail stimulus, to an increase in the flow of calcium ions into the terminal, leading to firing and transmission of the nerve impulse across the synapse.

The underlying mechanism for more complex aspects of learning and memory remains in doubt. However, one possible mechanism is suggested by the effect

known as *long-term potentiation* (LTP), a phenomenon first discovered by Bliss and Lomo (1973). While working on the hippocampus of the rabbit (a part of the brain that appears to be heavily involved in learning and memory), they found that intense electrical stimulation of connected areas resulted in hippocampal cells responding more strongly to stimuli than they had done previously. This enhanced response lasted for days, weeks, and even longer, suggesting that it might be a mechanism for long-term learning.

Subsequent research has indicated that LTP depends on the activity of the receptors on both sides of the synapse. When the presynaptic sending mechanism receives high-frequency stimulation, it releases the neurotransmitter glutamate. For LTP to occur, however, the post-synaptic or receiving neuron must also be operating at the appropriate level. The relevant post-synaptic receptors are sensitive to a substance known by the abbreviation NMDA (N-Methyl-D-Aspartate), and firing depends on having exactly the right balance of ions in the receptor channel. When both pre- and post-synaptic circumstances are right, the nature of the synapse changes, so that in future a much weaker pre-synaptic stimulus will cause the post-synaptic neuron to fire.

The fact that the cells associated with LTP are particularly numerous in the hippocampus, which is assumed to be crucially involved in learning and memory, provides some encouragement for believing that this may indeed be a basic learning mechanism. In a classic book published in 1949 the Canadian psychologist Donald Hebb speculated that a mechanism such as this might underlie the process



The Canadian psychologist Donald Hebb whose ideas, first proposed in the 1940s, are still highly influential. (Photograph courtesy University of Cambridge, Department of Experimental Psychology)

of learning. Since that time a number of computer-based learning models have been developed using Hebb's ideas.

How psychologists study memory

Although some psychologists are involved in trying to understand the physiological basis of memory, this approach will play little part in the remainder of the present account of human memory. If psychologists do not study memory by examining its physical or biochemical characteristics, how do they arrive at their findings? Do they simply ask people how they remember things? On the whole they do not. Although it is unwise to ignore people's comments on how they learn or remember, experience has shown that this kind of information is an unreliable source of evidence.

Consider, for example, the question of visual imagery. In the nineteenth century Sir Francis Galton did a classic study which involved writing to a large number of eminent men and asking them to try to conjure up an image of their breakfast tables on the morning they received this unusual request (Galton, 1883). They were asked to comment at length on the richness, detail, and vividness of the image they created, and enormously wide differences were observed, some respondents reporting that their remembered breakfast table was almost as vivid as their direct perception of it, others reporting no imagery at all. Subsequent work has confirmed that people differ extremely in the reported vividness of their imagery. Yet attempts to relate this to their memory abilities have proved universally disappointing. For example, Sir Frederick Bartlett (1932) had his subjects try to recall stories, and noted that although those who claimed to have vivid visual imagery were on the whole more confident in their powers of memory than those without such imagery, they were no more accurate in their recall. A much later study by three American investigators, di Vesta, Ingersoll, and Sunshine (1971), looked at the relationship between stated vividness of imagery, and a range of other tests. Memory performance was not related to vividness of imagery and indeed the only measure that did show a relationship to imagery was a measure called 'social desirability', claimed to be an indicator of the extent to which subjects attempt to be obliging and give socially acceptable answers! Hence although large differences in the reported use of visual imagery exist, they do not seem to tell us very much about the functioning of human memory, whereas other methods based on performance rather than self-report have proved very fruitful, as we shall see.

If people's comments on their own memory are unreliable, how does one investigate memory? The answer is, by setting subjects various memory tasks and scoring how well or badly they do them. Sometimes experiments take advantage of participants' differential memory abilities, but more frequently they take advantage of the difficulties people have and the mistakes they make when asked to remember certain types of material. If I were to present you with a string of consonants, say *l r p f q h*, and ask you to repeat them back to me, you would probably get most of them right, but your occasional errors would be revealing;

for example, you would tend to substitute *b* for *p* or *s* for *f*, the errors being similar in sound to the correct item. I would conclude from this, as Conrad and Hull (1964) did, that you used verbal or acoustic memory rather than visual memory in order to remember the letters.

Another way of exploring human memory is to use a method known as 'selective interference'. I might, for example, want to test the idea that people remember addresses or telephone numbers by repeating them under their breath. I could prevent such repetition and see if it impairs recall. Ask someone to articulate an irrelevant word such as 'the' while they are trying to rehearse or write down a telephone number and their performance drops dramatically.

The chapters that follow are concerned with human memory for a wide range of material, but you will no doubt notice rather a lot of work on memory for verbal material. The reasons for this are twofold. First, there is no doubt that verbal coding plays an extremely important part in human memory. Even when one is remembering visually presented items, or recalling actions or incidents, there is a strong tendency to supplement other aspects of memory by verbalising, turning what may be initially purely a visual task into a combined visual and verbal one. The second reason for a predominance of verbal material is more practical. On the whole it is much easier to select and control verbal material than it is to manipulate visual, tactile, or auditory stimuli. Suppose, for example, one wants to study the effects of the familiarity of the material one is using. Information exists on the frequency with which every word in the English language is used, allowing us to quantify the familiarity variable very simply. Similarly, data exist on the age at which people tend to first encounter particular words, on the tendency of a word to evoke a visual image, and so on, making verbal material by far the easiest to manipulate in experimental settings.

Another advantage of using words and letters as test materials is that they can be presented in the spoken or written mode, and can be recalled in either. With visual material, however, we are limited to one mode of presentation, and typically to testing by recognition, as it is hard for a subject to indicate visual recall other than by drawing, which has major limitations unless one is a talented artist.

As will become clear from the chapters that follow, psychologists investigating memory are largely in the position of someone trying to understand the functioning of a machine without being able to look inside it. Consequently they have to rely on manipulating the tasks that the machine must carry out, and on carefully observing its behaviour under various conditions. Such an approach demands considerable patience and ingenuity but, as I hope you will agree by the end of this book, it can produce important insights.

The nature of human memory

Although the plight of Clive Wearing argues strongly for the general importance of memory, it does not tell us much about the detailed nature of the systems underlying human memory. Suppose we wanted to replace his faulty memory,

what characteristics should our memory prosthesis provide? Another way of asking the same question would be to take an evolutionary perspective and speculate on what memory functions might prove useful to an organism evolving in a complex and varied, but nevertheless structured, world. Let us assume that the organism has been given a number of sensory channels—vision, hearing, touch, and smell, for example. Information from these various channels ought, in principle, to be related; objects such as trees can be seen and touched, and indeed heard as the wind rustles through their leaves. Appreciating this and creating some representation of an object is likely to require memory, at least of a temporary form, a short-term or working memory that will allow the organism to pull together information from a number of sources and integrate it into a coherent view of the surrounding world.

It would also be useful to build up, over time, some knowledge about the world. Given that the world is at least partly predictable, it would be advantageous to learn which foods are good and which cause illness, for example. In short, some form of long-term memory would also be useful. Such long-term learning can be of several different kinds, however, and each kind seems to obey different rules. Clive Wearing retains his skills as a musical performer, but his capacity to retrieve facts about the past (details of his musical achievements, the names of great composers) is grossly impaired.

Clues as to the structure of the complex alliance of systems that we call human memory are provided by other individuals with less dramatic memory problems, and of course by the study of the memory processes of normal people, as will become clear in later chapters. However, it might be helpful at this point to give a brief overview of the probable psychological structure of human memory, so as to provide a general framework within which the rest of the book can be interpreted.

The realisation that memory can be fragmented into subcomponents is not a new one; it was proposed in 1890 by the great American psychologist William James, and again by Donald Hebb in 1949. Experimental evidence for the fractionation of human memory has developed principally over the last 30 years. Until the 1960s many psychologists felt that it was unnecessary to assume more than one kind of memory, but by the early 1970s some form of distinction between long- and short-term memory was widely accepted. By the end of the decade both short- and long-term memory systems had been subdivided further.

Although not everyone would be entirely happy with the structure I am going to propose, there is by now broad agreement that some such fractionation is useful. While I like to refer to separate systems and subsystems, other theorists might prefer to emphasise the different processes involved in remembering, rather than the underlying structures within which such processes operate. However we are likely to agree on virtually all of the information about human memory that I shall be presenting in this book. If there is disagreement, it is most likely to occur in areas where the evidence is too scanty to allow us to decide between a number of plausible alternatives.

Consider, for example, Clive Wearing's inability to remember what he has had for breakfast. Why does he have this problem? One possibility is that the experience of having breakfast never registers in his brain; in other words no memory trace is laid down. A second possibility is that a trace is laid down, but fades away very rapidly. A third possibility is that the memory trace is there, but cannot be accessed or retrieved. The memory trace may be like a book in a library with no catalogue system. As we shall see later, deciding which, if any, of these scenarios is responsible for an observed memory failure is extremely difficult. Nevertheless it is important and potentially helpful to bear in mind that any adequate memory system must be capable of registering information presented, storing that information over time, and retrieving it when required.

How many kinds of memory?

Intense controversy during the 1960s led to a whole range of memory models of a broadly similar form. They tended to assume three kinds of memory—sensory memory, short-term memory, and long-term memory—and are well represented by the model proposed by Richard Atkinson and Richard Shiffrin (1968) (see Fig. 1.1). Because it was both typical and influential, this model acquired the nickname 'the modal model'. In this model it is assumed that information comes in from the environment through a parallel series of brief sensory memory stores, or registers, and goes into a common short-term store. This is assumed to act as a working memory, capable of manipulating information and relating it to long-term storage. Indeed the short-term store forms a crucial link in this model;

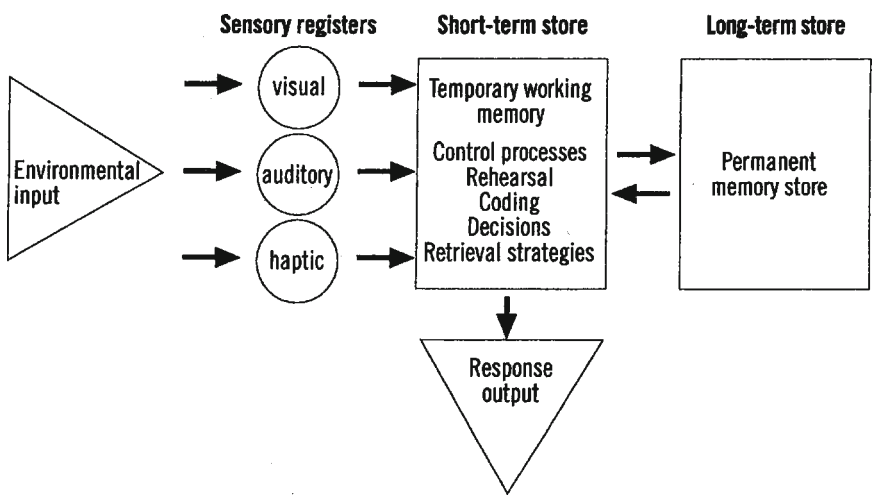


FIGURE 1.1 The flow of information through the memory system, as conceptualised by Atkinson and Shiffrin

without it, neither the learning of new material nor the recollection of old information is possible. We will consider each of these sub-components separately.

Sensory memory

When you go to the cinema you see what appears to be a continuous scene in which people apparently move quite normally. What is actually presented to your eyes, however, is a series of frozen images interspersed with brief periods of darkness. In order to see a continuously moving image it is necessary for the brain's visual system to store the information from one frame until the arrival of the next. The visual store responsible for this is one of a whole series of sensory memory systems that are intimately involved in our perception of the world.

Even within visual memory there are probably many components capable of storing visual information for a brief period of time. If you move the end of a brightly glowing cigarette in a darkened room you will find that a trace is left behind—you can write a letter of the alphabet and someone else will 'see' the letter. This effect was used to measure the duration of the visual sensory memory trace as long ago as 1740 by a Swedish investigator, Segner, who attached a glowing ember to a rotating wheel. When the wheel was rotated rapidly, a complete circle could be seen, because the trace left at the beginning of the circle was still glowing brightly by the time the ember returned to its starting point. If the wheel was moved slowly, only a partial circle would be seen, because the trace of the first part had faded by the time the ember returned to its starting point. By rotating the wheel at a speed that just allowed a complete circle to be

The persistence of the image of the sparkler allows her to 'draw' a series of circles. (Photograph courtesy Robert Harding, photographer Nigel Francis)

drawn, and measuring the time taken for one revolution, Segner was able to estimate the duration of this brief sensory store. He found it to be approximately one-tenth of a second.

This phenomenon, known as 'persistence of vision', can be demonstrated even more simply. Spread out the fingers of your hand and pass them in front of your eyes. Do so slowly at first and you will notice that the scene seems unstable and tends to jump about. Now move your fingers to and fro rapidly. You will then see what appears to be the normal scene, although possibly a little blurred. In the rapid movement condition, the scene is interrupted only briefly, allowing the information registered by the retina to be refreshed before it fades away.

The fact that the visual trace of a bright light persists after the light has moved on, implies that it has been stored in some way. The nature of this storage was explored in an elegant series of experiments conducted by George Sperling (1960) in which subjects were shown three rows of four letters for a very brief period, 50 milliseconds, followed by a blank white field. When asked to recall the items, subjects could typically manage only four or five of the twelve letters. Was this because they had only seen four or five, or because they had forgotten the remainder? Sperling tested this by changing his recall instructions. Instead of asking for all the letters, he requested only a single row, delivering a high tone to indicate the top row, a medium tone for the middle, and a low tone for the bottom row. Under these circumstances, subjects recalled an average of three of the four items from the relevant line. As the subject did not know in advance which line he was going to be tested on, it implied that some three quarters of the letters had been perceived, but lost during the process of recall.

In a subsequent experiment, Sperling varied the delay between presenting the letters and giving the cue. He argued that if the trace of the letters was decaying, then performance should decline as the delay increased. With a bright field before and after the letters, Sperling found that performance declined rapidly until, after half a second, it was no better than the level of performance obtained when subjects were asked to recall all the items. In a later study, Sperling (1963) preceded and followed the letters with a dark visual field. As Figure 1.2 shows, under these circumstances performance was considerably better, only levelling off after four or five seconds.

Sperling interpreted his data in terms of a brief visual store from which information is subsequently transferred to a more durable non-visual system. The store is disrupted by a bright line, hence resulting in much more rapid forgetting.

There are at least two, and probably more, components to sensory visual memory, or *iconic memory*, as it is sometimes called. One of these appears to depend on the retina of the eye and is primarily influenced by the brightness of the stimulus presented. The second one occurs at a point in the brain after information from both retinas has been received and integrated. This component is much more sensitive to pattern than to brightness, and represents the operation of a system involved in shape recognition (Turvey, 1973).

An analogous series of sensory memories occurs in hearing. If I were to present an extremely brief click in one corner of the room, you would be very

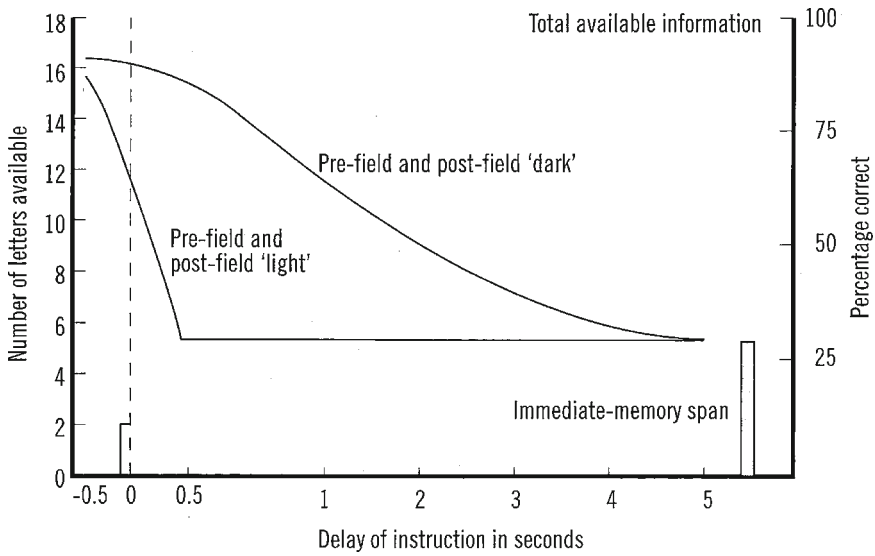
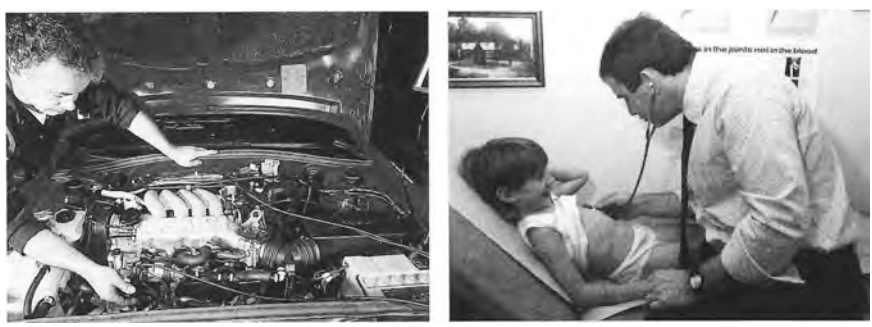


FIGURE 1.2 Loss of information from visual sensory memory. In this experiment, 16 letters were presented visually. When the letters were preceded and followed by a dark visual field, the sensory or iconic memory trace lasted for several seconds. When the field before and after was bright, information was lost in half a second. (Based on Sperling, 1963)

good at deciding from which direction the click came. In order to do this, you would use the tiny difference in the time of arrival of the click at your two ears, performing a task analogous to the use of sonar to locate the position of a ship. However, in order to make use of this discrepancy in time of arrival of the click at the two ears, it is necessary to have a system that will store the first click until



A mechanic's car tuning and a doctor's use of the stethoscope both rely on a good memory for sound and rhythms. (Photograph courtesy Robert Harding, photographers Don Williams and Jane Legate)

the arrival of the second, allowing this difference to be estimated extremely accurately. Although one would not term this a memory system in the usual sense, it certainly is a system for storing and retrieving information, and as such can legitimately be described as a very brief sensory memory system.

The existence of a rather more durable auditory memory system can be shown as follows. Suppose I were to read out to you a series of nine-digit telephone numbers. The chances are that you would get most of the digits of each number right, but would tend to make errors. If I then switched to a system of presenting the numbers visually, one digit at a time, you would find that you made rather more errors, particularly towards the end of the sequence. The graph in Fig. 1.3 shows a typical error pattern for nine-digit sequences both read and heard.

The most striking feature of the graph is the discrepancy between the two modes of presentation in the case of the last item presented. When this is spoken, it is almost always correctly recalled; when it is presented visually, errors are very numerous. The reason for this appears to be that when the sequence is spoken, the last item can still be recovered from a brief auditory memory, sometimes referred to as *echoic memory* because it is rather like an echo lingering on after the item has been spoken. The echo is limited to one or possibly two items. Consequently it can be wiped out by presenting a further irrelevant item afterwards. Echoic memory is left holding the irrelevant item instead of the last digit. Hence if I had spoken the sequence of digits to you, and then followed it with the spoken instruction 'Recall', the 'echo' of the last digit would have disappeared. The system involved in echoic memory of this type seems to be particularly geared to speech, as a simple but meaningless spoken sound such as

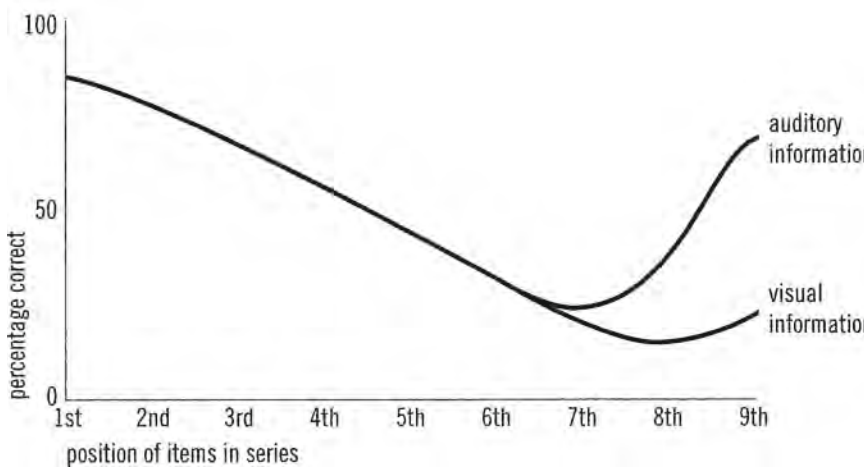


FIGURE 1.3 Auditory information lingers longer in sensory memory than visual information. This explains why the later words in a series are better remembered if they are heard rather than read

'bah' will disrupt performance whereas a pure tone of similar loudness and duration will not. A sequence of spoken digits is better remembered than a sequence of digits presented visually because auditory sensory memory appears to be more durable than visual memory (Crowder & Morton, 1969).

Auditory sensory memory is not limited to speech sounds. Suppose you are dubious about some component in your car engine and you listen to it while driving. What you will be trying to perceive is a repeated sound embedded in the relatively random engine noise. In order to perceive the repetition you need to be able to store a long enough 'bite' of noise to be able to detect the one feature that seems to be recurring. This effect has been used to study auditory memory. The listener is presented with a tape which recycles a sample of randomly fluctuating noise and the size of the sample is then systematically varied. If the sample is half a second long, the listener is required to perceive features that recur every half second. To be able to do this, he or she needs an auditory memory system that stores at least half a second's worth of sound. If the sample lasts for a full second, a more durable memory store would be needed to detect the rhythmic fluctuation. When faced with this task, subjects vary somewhat in their capabilities, but on average can detect repetitions separated by up to three seconds, indicating an auditory memory system of at least this duration (Guttman & Julesz, 1963).

Although we have touched only briefly on sensory memory, we shall not be returning to it. It is an important component of our overall memory apparatus, but it is probably best seen as part of the process of perception. To explore it further would demand far more detailed analysis of perception than is possible within the limits of the present book.

Short-term memory

To understand this sentence, you need to remember the beginning until you get to the end. Without some kind of memory for the words in it and the order in which they occur, it would be incomprehensible.

Suppose I ask you to multiply 23 by 7 in your head. Try looking away from the page and doing this. First of all, you need to remember the numbers involved. Then you will probably multiply 3 by 7, and remember that the answer is 21. Then you will remember the 1 and carry the 2. Then you will multiply the 2 by 7 and retrieve the 2 you carried, making 16. Then you will retrieve the original 1 and come up with the answer 161. All of this involves a good deal of temporary storage of numbers, all of which need to be retrieved accurately and at the appropriate time. Having completed the sum, there is no further need to retrieve information such as which number was carried, and after a couple of similar sums it is unlikely that you will be able to remember this information.

In both language comprehension and arithmetic, therefore, there is a need for the temporary storage of information in order to perform various functions subsidiary to understanding or calculating. Once the task has been achieved, the

subsidiary information is no longer required. Short-term or *working* memory is the name given to this system, or, perhaps more appropriately, set of systems. Information that is essential for a brief period of time is very temporarily stored, then becomes quite irrelevant.

To what extent does short-term memory represent a system that is quite different from long-term memory? Here again there has been considerable controversy in recent years. One view is that short-term memory represents the same system as long-term memory, but is used under rather special conditions which lead to very little long-term retention. The alternative view, which I myself support, is that long- and short-term memory involve separate systems, although they are very closely integrated in operation. I myself would further argue that short-term memory represents not one but a complex set of interacting subsystems which I shall refer to as working memory.

Long-term memory

Of the three types of memory—sensory memory, working memory, and long-term memory—the one that corresponds most closely to the lay person's view of memory is long-term memory. This represents information that is stored for considerable periods of time. Indeed, as we shall see later, some theorists claim that information in memory never disappears, but simply becomes less and less accessible. Remembering your own name, how to speak, where you lived as a child, or where you were last year or indeed five minutes ago are all assumed to depend on long-term memory. Such memory is primarily concerned with storing information, unlike sensory memory and short-term memory where the storage is an incidental feature of other aspects of the system.

Strategies in games like chess depend on working memory. (Photograph courtesy TRIP, photographer M. Bourdillon)

To an experimental psychologist the phrase 'long-term memory' refers to information that is stored sufficiently durably to be accessible over a period of anything more than a few seconds. The reason for this is that, on the whole, memory tested after one or two minutes seems to behave in much the same way as memory tested after one or two days, or years. The same does not apply, as we shall see in due course, to memory tested after one or two seconds, or even milliseconds. Is long-term memory a unitary system? This is still a controversial question. Distinctions of at least two types are commonly made, however.

Episodic and semantic long-term memory. A few years ago Canadian psychologist Endel Tulving (1972) made a useful distinction between two types of long-term memory: episodic memory, which involves remembering particular incidents, such as going to the dentist a week ago, and semantic memory, which essentially concerns knowledge about the world. Knowing the meaning of a word or the chemical formula for salt or the capital of France would all be examples of semantic memory. There is no doubt that there are differences between specific personal memories of individual incidents and generalised knowledge of the world, which has often been acquired over a considerable period of time. Whether these represent separate memory systems or different aspects of a single system is still uncertain. However, the distinction is a convenient and useful one. In this book semantic memory has a chapter of its own.

A great deal of research on human memory has used verbal materials, because words are easy to present and people's responses are easy to record and score. In recent years researchers have increasingly asked whether memory for verbal materials is characteristic of all memory, and in particular whether memory for non-verbalisable sensory experiences relies on quite different memory systems. Undoubtedly we can remember the taste of cheese or the smell of burning rubber or the sound of the sea breaking on a rocky shore without using verbal descriptions of these experiences. Are there separate auditory and visual memory systems, or an all-embracing memory system that is capable of encoding all our experiences? Taking this latter view, much verbal learning is verbal only in as much as the material is presented verbally and subjects respond verbally; what is stored is the experience conjured up by the verbal material. Fortunately the general rules that apply to the learning of verbal material also seem to apply, at least broadly, to remembering pictures or sounds, so the overall conclusions drawn in the chapters that follow are still likely to be valid whether we conclude that long-term memory is a unitary, dual, or multiple system.

Implicit and explicit memory. It has been known for many years that densely amnesic patients such as Clive Wearing may still be capable of certain kinds of new long-term learning. The learning of motor skills such as typing is typically preserved, as is a whole range of phenomena known as priming. This term refers to the observation that when a word or object is seen or heard more than once, it will be seen or heard more readily on second and later occasions. Hence if you

have recently read the word *rabbit*, then you will be better able to perceive it if I present it very briefly, and will be more likely to come up with the word if asked to produce something that will fit the pattern of letters R–B– –T, than a subject who has seen a quite different word (Roediger, Weldon, Stadler, & Reigler, 1992).

Learning measured in this way is called implicit. Because the subject is not asked about earlier presentations of material to be learned, their influence is reflected indirectly in the speed or nature of subsequent performance, typically in a non-memory task. Such learning is not affected by many of the factors that are important when learning is measured by recall or recognition. Processing a word in terms of its meaning, for example, enhances subsequent recall, but does not influence the magnitude of priming, whereas changing the physical presentation of the word, changing the typeface in which it is printed, for example, tends to reduce priming, but has little or no effect on recall (Roediger, 1990).

Research in this area is currently extremely active. Some theorists argue that implicit and explicit learning reflect a single system operating under rather different constraints, while others argue for different learning processes. Typically the single system position is held by researchers who work principally with normal subjects, while those with a strong interest in neuropsychological deficits are more likely to advocate an approach based on two or more learning systems. My own current view is that both episodic and semantic memory are based on a single system that is damaged in amnesic patients, but that a number of implicit learning processes occur; what these have in common is the fact that they do not rely on explicit episodic memory. However, this issue will be discussed in more detail in Chapter 4. The area is currently bedevilled by problems of terminology. While most people agree that there is an important distinction, they tend not to agree on how it is best conceptualised. Consequently they tend to use somewhat different terms to refer to the same phenomena.

Although there is disagreement about the theoretical interpretation of explicit and implicit learning, most people would agree that the preserved learning in amnesic patients is characterised by tasks in which the learning is measured indirectly. The subject does not need to remember having encountered the situation before in order to perform well on a skill task such as typing, for example, or to show a priming effect. In contrast, amnesic patients perform badly on tests that require them to recollect the learning experience—they would find it difficult to recall a newspaper story, for example, or decide whether a particular word had been presented earlier in a test session. For this reason some theorists prefer to use the terms *direct* and *indirect* (rather than *explicit* and *implicit*) to distinguish between the two types of learning and memory.

Another way of interpreting the two types of learning and memory is to call them *declarative* and *non-declarative*. Declarative memory refers to memory for facts or events, and non-declarative to the rest. I myself am sympathetic to this distinction, but must confess that I find the labels somewhat cumbersome.

In the chapters that follow I will describe short-term or working memory, and then go on to consider various aspects of long-term learning and memory. I shall then apply what we have learned to such practical issues as interpreting the testimony of witnesses, understanding amnesia, and studying memory in children and in the elderly.

Summary

Memory does not comprise a single unitary system, but rather an array of interacting systems, each capable of encoding or registering information, storing it, and making it available by retrieval. Without this capability for information storage, we could not perceive adequately, learn from our past, understand the present, or plan for the future.

Research on the neurophysiological basis of learning and memory is progressing, initially relying largely on understanding learning in simpler organisms such as the sea slug *Aplysia*, where the neurobiology of adaptation and simple conditioning is beginning to be understood. In more complex organisms, there is considerable interest in long-term potentiation (LTP) as a possible model of the learning process, but while this is a plausible candidate for a learning mechanism, there is still controversy over its interpretation.

In the case of the psychological study of memory, there is considerable agreement that it can broadly be divided into: (1) sensory memory; (2) short-term or working memory; and (3) long-term memory. Sensory memory refers to the role of storage in the processes involved in perception, with the term iconic memory referring to visual sensory memory, and echoic memory to its auditory equivalent.

Short-term or working memory refers to the temporary storage of material necessary for performing a range of complex tasks such as comprehension, reasoning, and long-term learning.

Long-term memory refers to more durable encoding and storage systems. Distinctions within long-term memory include that between episodic memory, the capacity to recollect experience, and semantic memory, stored knowledge of the world. There also appear to be a number of parallel systems that are capable of implicit memory, whereby a subject may not be able to recollect the learning experience, but can nonetheless demonstrate learning through a change in behaviour.

Suggested further reading

Baddeley, A.D. (1997). *Human memory: Theory and practice* (Rev. ed., pp. 9–27). Hove, UK: Psychology Press.
Chapter 2 provides a more extended overview of sensory memory, the link between memory and perception.

Rose, S. (1992). *The making of memory*. London: Bantam.
A popular account of the neurobiological basis of memory.

2

SHORT-TERM MEMORY

How long is the present? A minute? A second? A millisecond? Or is it infinitesimally small? Suppose we hear the word 'bicycle' spoken. We do not have the sensation of needing to pull the initial syllable 'by' out of memory when we come to the final syllable—the whole word appears to be present at the same time. William James referred to this sensation as 'the specious present', specious because it seems plausible, though it is literally false, that the beginning and end of the word are present at the same time. Sir Francis Galton, the nineteenth-century British scientist, gave the following description of a similar phenomenon (Galton, 1883, p. 57):

William James. (Photograph courtesy Mary Evans Picture Library)

> There seems to be a presence-chamber in my mind where full consciousness holds court, and where two or three ideas are at the same time in audience, and an ante-chamber full of more or less allied ideas, which is situated just beyond the ken of full consciousness. Out of this ante-chamber the ideas most nearly allied to those in the presence-chamber appear to be summoned in a mechanically logical way, and to have their turn of audience.

This concept of limited consciousness is closely related to but not identical with the concept of short-term memory (STM), a system for storing information over brief intervals of time. The nature of consciousness is a fundamental and fascinating problem. In considering short-term memory, however, we will be looking at one aspect of the problem, namely the characteristics of the system that allow the holding and manipulation of limited amounts of information. It is as if the system can grasp fleeting ideas which would otherwise slip into oblivion, hold them, relate them, and manipulate them for its own purposes. The number of items or ideas that can be grasped is limited, but capacity can be supplemented in various ways.

Digit span

The question of the capacity of immediate memory was one that preoccupied a number of philosophers during the nineteenth century. Sir William Hamilton, for example, observed that if one flung a handful of marbles on the ground, the maximum number that could be perceived reasonably accurately would be about seven. The first systematic experimental work to be done on this problem was carried out in 1887 by a London schoolteacher, John Jacobs, who was interested in measuring the mental capacity of his pupils. He devised a technique, the digit span, which has played an important role in psychology ever since. The subject is presented with a sequence of digits and required to repeat them back in the same order; the length of the sequence is steadily increased until a point is reached at which the subject always fails; the sequence length at which the subject is right half the time is defined as his or her digit span. Try it for yourself. Read out loud the digit sequences shown in Fig. 2.1 at a steady rate. After each sequence, close your eyes and try to repeat the numbers in the correct order. Note in each case whether you get the sequence completely correct or not. If you do, move on to the next length of sequence. If you make a mistake, try the next sequence of the same length, and continue testing yourself until you reach a length at which you are always incorrect. Your span is the length at which performance reaches its limit, which for present purposes can be regarded as the longest sequence you recall correctly on at least one of the three permitted attempts.

Most people can manage six or seven digits, but there is quite a large range of capacity, with some people managing only four or five and others getting up to ten or more. Needless to say, tests would normally be carried out in much more controlled conditions than this.

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

FIGURE 2.1 Random digit sequences

If you speak the sequences aloud, you will probably do somewhat better than if you simply read them to yourself. The reason for this is that articulating and hearing the sounds of the numbers registers them in the brief echoic memory store described in the previous chapter.

Another way of improving your performance would be to group the digits rhythmically. This technique appears to help reduce the tendency to recall them in the wrong order. Studies comparing different modes of grouping seem to come up with the conclusion that grouping in threes is best and that even a tiny gap between successive groups is helpful, provided the listener can hear it (Wickelgren, 1964). So if you are telling someone your telephone number and you want to ensure that they write it down correctly, group it in threes, or if it is not divisible by three, in threes and twos. Having done so, you would be wise to check it, as there is a surprisingly high error rate in reproducing telephone numbers, even when one is simply remembering a number for the brief period needed to copy it from one sheet of paper to another.

The role of rhythm in memory is one that we rather tend to neglect, possibly because it is associated with nineteenth-century ideas of memory drill which emphasised the parrot-like repetition of often useless information. Rhyme and rhythm are what make poetry particularly easy to commit to memory. Rhythm certainly played an important role in the memory of the late Professor A.C. Aitken of Edinburgh University. Aitken was a very talented mathematician and had amazing memory abilities; he was, for example, a lightning calculator. One of Aitken's mnemonic feats was to recall, to the first thousand decimal places, the value of pi (the symbol of the ratio of the circumference of a circle to its diameter). Ian Hunter, a psychologist who studied his remarkable talents, reports that Aitken thought this 'a reprehensibly useless feat had it not been so easy.' Aitken discovered that by arranging the digits in rows of 50, with 10 groups of 5 digits in each row, and reading them over in a particular rhythm, they were very easy to memorise: