ALAN BADDELEY, MICHAEL W. EYSENCK, AND MICHAEL C. ANDERSON

MEMORY

Third Edition

A **Psychology Press** Book

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MEMORY

The third edition of *Memory* provides students with the most comprehensive introduction to the study of human memory and its applications in the field. Written by three leading experts, this bestselling textbook delivers an authoritative and accessible overview of key topic areas.

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Key features of this edition:

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- it has new material addressing current research into visual short-term and working memory, and links to research on visual attention;
- it includes content on the state-of-play on working memory training;
- the chapter on "memory across the lifespan" strengthens the applied emphasis, including the effects of malnutrition in developing nations on cognition and memory.

The third edition is supported by a Companion Website providing a range of core resources for students and lecturers.

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MEMORY

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THIRD EDITION

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MICHAEL W. EYSENCK

AND MICHAEL C. ANDERSON

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"For Hilary"—Alan Baddeley

"To Christine with love"—Michael W. Eysenck

"To Max, whose toddlerhood I hope always to remember"—
Michael C. Anderson

CONTENTS

ABOUT THE AUTHORS

As described in his recent memoirs, *Working Memories: Postmen, Divers and the Cognitive Revolution*, Alan Baddeley graduated in Psychology from University College London. He spent the following year in Princeton, the first of five such stays in the US. He returned to a post at the Medical Research Council Applied Psychology Unit (APU) in Cambridge, completing a Ph.D. concerned with the design of postal codes. He continued to combine applied research, for example on deep-sea diving, with theoretical issues such as the distinction between long- and short-term memory. After moving to the University of Sussex, he and Graham Hitch proposed a multicomponent model of working memory. He also began working with amnesic patients, continuing both these lines of research when he moved, first to a chair at the University of Stirling, then returning to the APU in Cambridge. After 20 years as its director, he moved first to the University of Bristol, then to his current position in York where he has resumed his collaboration with Graham Hitch. He was awarded a CBE for his contributions to the study of memory, is a Fellow of the Royal Society, the British Academy, the Academy of Medical Sciences, and the American Academy of Arts and Sciences.

Michael W. Eysenck graduated from University College London. He then moved immediately to Birkbeck University of London as a lecturer, where he completed his Ph.D. on the von Restorff and "release" memory effects. His research for several years focused on various topics within memory research (e.g., levels of processing; distinctiveness). However, for many years his research has focused mainly on anxiety and cognition (including memory). Most of this

research has involved healthy populations but some has dealt with cognitive biases (including memory ones) in anxious patients. This research has been carried out at Birkbeck University of London and at Royal Holloway University of London, where he has been Professor of Psychology since 1987 (Head of Department, 1987–2005). However, it was started during his time as Visiting Professor at the University of South Florida. He has published 40 books in psychology (many relating to human memory), including two research monographs on anxiety and cognition. He has been in *Who's Who* since 1989.

Michael C. Anderson received his Ph.D. in Cognitive Psychology from the University of California, Los Angeles in 1994. After completing a postdoctoral fellowship in cognitive neuroscience at the University of California, Berkeley, he joined the psychology faculty at the University of Oregon, where he was director of the Memory Control Laboratory through 2007. He is now Senior Scientist and Programme Leader at the MRC Cognition and Brain Sciences Unit in Cambridge, England. His research investigates the roles of inhibitory processes as a cause of forgetting in long-term memory. His recent work has focused on executive control as a model of motivated forgetting, and has established the existence of cognitive and neurobiological mechanisms by which we can willfully forget past experiences. This work begins to specify the mechanisms by which people adapt the functioning of their memories in the aftermath of traumatic experience.

PREFACE TO THE THIRD EDITION

The current edition uses the same broad structure as the two previous editions, but with a somewhat clearer delineation of the various sections. I continue to be responsible for the two introductory chapters involving relatively modest changes, followed by the chapter on short-term memory which now contains more on visual short-term memory. The working memory chapter is updated in the light of recent developments including current attempts to compare and contrast different theoretical approaches. The chapters covering the basic study of long-term memory are all now covered by Michael Anderson, who provides a more coherent overview from someone who was very actively involved in recent advances in the area and its links to neuroscience. The chapter on learning has been significantly updated to include exciting work on retrieval-based learning, cortical plasticity, spacing learning, the impact of motivation on the neural mechanisms of encoding, divided attention, an expanded treatment of implicit forms of memory, and the latest cutting-edge developments of the cellular basis of plasticity. The chapter on episodic memory has been expanded to include coverage of the neural mechanism of episodic encoding and consolidation, and innovative work identifying the neural basis of schemas and how they enhance retention by hastening consolidation. The chapter on autobiographical memory now includes expanded coverage of emotional effects, new reports of severely deficient autobiographical memory, updated coverage of psychogenic amnesia, and the latest findings in the neural basis of autobiographical memory. The retrieval and forgetting chapters have been updated with recent developments in these area at the cognitive, brain systems, and cellular levels. Michael Eysenck continues to cover theory and research on semantic memory, which has increasingly benefitted from the approach of cognitive neuroscience. He also continues to cover chapters on the application of the study of memory beyond the laboratory to eyewitness testimony, prospective memory, and memory improvement, areas that have seen impressive advances in the years since the previous edition. He has however passed on to me the chapter on memory in childhood, which I have adopted as part of a three-chapter block on memory development and decline. I take a slightly more applied approach reflecting my interest in the effect of disease and malnutrition on early development and the potential contribution of the study of memory to practical aspects of child development. The memory and aging chapter contains more on recent attempts to minimize the effects of age on cognition. The third chapter in this section focuses principally on applied issues of memory decline with particular reference to Alzheimer's disease and to traumatic brain injury concluding by discussing methods to help people deal with failing memory.

Once again I am heavily indebted to Lindsey Bowes for her contribution at levels ranging from typing my mumbled dictation through helping search for references to rescuing me from frustrations induced by my very limited IT skills. I again am also grateful to my wife Hilary who continues to tolerate my refusal to behave like a sensible retiree.

I (Michael Eysenck) am indebted to my wife Christine in every way for her support for my time-consuming book-writing efforts. The completion of this book has given me more time to spend with our delightful grandchildren Sebastian and Clementine.

Michael Anderson is grateful to his partner Nami for her considerable support in enabling work on this text, and to his son Max, who illustrates daily the power of learning, and who has provided inspiration for many examples in this book.

Finally, we are grateful to the staff at Taylor & Francis for their overall management of the project. In particular we would like to thank Ceri McLardy and Kirsten Shankland for keeping us on track with their customary efficiency and good humour and to the Production Editor Pip Clubbs for her friendly efficiency during the final stages of producing the book.

Alan Baddeley
York, 2020

Contents

CHAPTER 1

WHAT IS MEMORY?

Alan Baddeley

Memory is something we complain about. Why? Why are we quite happy to claim "I have a terrible memory!" but not to assert that "I am amazingly stupid"? Of course, we do forget; we do sometimes forget appointments and fail to recognize people we have met in the past, and rather more frequently we forget their names. We do not, however, often forget important events; if the bridegroom failed to turn up for his wedding he would not be believed if he claimed to have forgotten. Consequently, failing to recognize an old acquaintance suggests that the person was perhaps not of great importance to us. The obvious excuse is to blame one's terrible memory.

In the chapters that follow, we will try to convince you that your memory is in fact remarkably good, although fallible. We agree with Schacter (2001) who, having described what he refers to as the seven sins of memory, accepts that the sins are in fact the necessary consequences of the virtues that make our memories so rich and flexible. Our memories might be less reliable than those of the average computer but they are just as capacious, much more flexible, and a good deal more user friendly. We forget more than computers, but we are likely to retain what is important and useful and forget unimportant details. We are good at rapidly encoding the context in which an event happens, what happened, when and where, so as to access when appropriate. We are good at remembering patterns of repeating events, a skill that helps us understand the world using this understanding to strip away redundant information and using the core meaning for future planning. Finally, we are very good at coping with forgetting by using knowledge to reconstruct partial memories. For these reasons, computer scientists are beginning to be interested in learning from human memory and importantly forgetting, with a view to potentially building some of these characteristics into computer memory (Mezaris, Niederee, & Logie, in press). Hence, despite their limitations our fallible memories play an absolutely crucial part in our ability to function independently in our complex world. Perhaps the most dramatic evidence for the usefulness of human memory comes from the plight of patients who have lost these capacities as in the case of Clive Wearing who has the misfortune to have had much of his memory capacity destroyed by disease (Wilson, Baddeley, & Kapur, 1995).

WHY DO WE NEED MEMORY?

Clive is an extremely talented musician, an expert on early music who was master of a major London choir. He himself sang and was asked to perform before the Pope during a papal visit to London. In 1985, he had the misfortune to suffer a brain infection from the herpes simplex virus, a virus that exists in a large proportion of the population, typically leading to nothing worse than cold sores but very occasionally breaking through the blood–brain barrier to cause encephalitis, an inflammation of the brain that can prove fatal. In recent years, treatment has improved, with the result that patients are more likely to survive, although often having suffered from extensive brain damage, typically in areas responsible for memory.

When he eventually recovered consciousness, Clive was densely amnesic and appeared to be unable to store information for periods longer than seconds. His interpretation of his plight was to assume that he had just recovered consciousness, something that he would announce to any visitor, and something that he repeatedly recorded in a notebook, each time crossing out the previous line and writing "I have now recovered consciousness" or "consciousness has now finally been recovered," an activity that continued for many, many years.

Clive knew who he was and could talk about the broad outlines of his early life, although the detail was very sparse. He knew he had spent four years at Cambridge University, but could not recognize a photograph of his college. He could remember, although somewhat vaguely, important events in his life such as directing and conducting the first modern performance of Handel's *Messiah* using original instruments in an appropriate period setting, and could talk intelligently about the historical development of the role of the musical conductor. However, even this selected knowledge was sketchy; he had written a book on the early composer Lassus, but could not recall any of the content. Asked who had written *Romeo and Juliet*, Clive did not know. He had remarried, but could not remember this. However, he did greet his new wife with enormous enthusiasm every time she appeared, even though she might only have been out of the room for a few minutes; every time declaring that he had just recovered consciousness.

Clive was totally incapacitated by his amnesia. He could not read a book or follow a television program because he immediately forgot what had gone before. If he left his hospital room, he was immediately lost. He was locked into a permanent present, something he described as "hell on earth." "It's like being dead—all the bloody time!"

However, there was one aspect of Clive's memory that appeared to be unimpaired, that part concerned with music. When his choir visited him, he found that he could conduct them just as before. He was able to read the score of a song and accompany himself on the keyboard while singing it. For a brief moment he appeared to return to his old self, only to feel wretched when he stopped playing. Over 20 years later, Clive is still just as densely amnesic but now appears to have come to terms with his terrible affliction and is calmer and less distressed.

ONE MEMORY OR MANY?

Although Clive's case makes the point that memory is crucial for daily life, it does not tell us much about the nature of memory. Clive was unfortunate in having damage to a range of brain areas, with the result that he has problems that extend beyond his amnesia. Furthermore, the fact that Clive's musical memory and skills are unimpaired suggests that memory is not a single simple system. Other studies have shown that densely amnesic patients can repeat back a telephone number, suggesting preserved immediate memory, and that they can learn motor skills at a normal rate. As we will see later, amnesic patients are capable of a number of types of learning, demonstrating this by improved performance, even though they do not remember the learning experience and typically deny having encountered the situation before. The evidence suggests, therefore, that rather than having a single global memory system, the picture is more complex. The first few chapters of this book will try to unpack some of this complexity, providing a basis for later chapters that are concerned with the way in which these systems influence our lives, how memory changes as we move through childhood to adulthood and old age, and what happens when our memory systems break down.

In giving our account of memory, we are of course presenting a range of psychological theories. Theories develop and change, and different people will hold different theories to explain the same data. As a glance at any current memory journal will indicate, this is certainly the case for the study of memory. Fortunately, there is a great deal of general agreement between different groups studying the psychology of memory, even though they tend to use somewhat different terminology. At this point, it might be useful to say a little bit about the concept of theory that underpins our own approach.

THEORIES, MAPS, AND MODELS

What should a psychological theory look like? In the 1950s, many people thought they should look like theories from physics. Clark Hull studied the learning behavior of white rats and attempted to use his results to build a rather grand general theory of learning in which the learning behavior of both rats and people was predicted using a series of postulates and equations that were explicitly modeled on the example set by Isaac Newton (Hull, 1943).

By contrast, Hull's great rival, Edward Tolman (1948), thought of rats as forming "cognitive maps," internal representations of their environment that were acquired as a result of active exploration. The controversy rumbled on from the 1930s to the 1950s, and then was abandoned quite suddenly. Both sides found that they had to assume some kind of representation that went beyond the simple association between stimuli impinging on the rat and its learned behavior, but neither seemed to have a solution to the problem of how these could be investigated.

The broad view of theory that we shall take is that theories are essentially like maps. They summarize our knowledge in a simple and structured way that helps us to understand what is known. A good theory will help us to ask new questions and that in turn will help us find out more about the topic we are mapping. The nature of the theory will depend on the questions we want to answer, just as in the case of maps of a city. The map that will help you travel by underground around London or New York looks very different from the sort of map that you would need if you wanted to walk, with neither being a direct representation of what you would see if you stood at a given location. That does not of course mean that they are bad maps, quite the opposite, because each map is designed to serve a different purpose.

In the case of psychological theories, different theories will operate at different levels of explanation and focus on different issues. An argument between a shopkeeper and customer, for example, would be explained in very different ways by a sociologist, who might emphasize the economic and social pressures, a social psychologist interested in interpersonal relationships, a cognitive psychologist interested in language, and a physiological psychologist who might be interested in the emotional responses of the two disputants and how these are reflected in the brain. All of these explanations are relevant and in principle should be relatable to each other, but none is the single "correct" interpretation.

This is a view that contrasts with what is sometimes called **reductionism**. This assumes that the aim of science is to reduce each explanation to the level below: Social psychology to cognitive psychology, which in turn should be explained physiologically, with the physiology then being interpreted biochemically and ultimately in terms of physics. Although it is clearly valuable to be able to explain phenomena at different but related levels, this is ultimately no more sensible than for a physicist to demand that we should attempt to design bridges on the basis of

KEY TERM

Reductionism: The view that all scientific explanations should aim to be based on a lower level of analysis: Psychology in terms of physiology, physiology in terms of chemistry, and chemistry in terms of physics.

subatomic particle physics, rather than Newtonian mechanics.

The aim of the present book is to outline what we know of the *psychology* of memory. We believe that an account at the psychological level will prove valuable in throwing light on accounts of human behavior at the interpersonal and social level, and will play an important role in our capacity to understand the neurobiological factors that underpin the various types of memory. We suggest that the psychology of memory is sufficiently understood to begin to interface very fruitfully with questions at both the social and neurobiological levels, and hope to illustrate this over the subsequent chapters.

HOW CAN WE STUDY MEMORY?

The case of Clive Wearing demonstrates how important memory is, and how complex, but leaves open the question of how it can best be studied. The attempt to understand human memory extends at least as far back as Aristotle, and forms one of the classic questions within the philosophy of mind, although without reaching any firm conclusions. This was vividly illustrated by a lecture on memory by the eminent philosopher A. J. Ayer that I attended as a student. He began rather unpromisingly, by declaring that memory was not a very interesting philosophical question. He seems to have demonstrated this pretty effectively as I can remember none of the lecture, apart from his statement that his memory was totally devoid of imagery, prompting a skeptical questioner to ask "If I tell you that the band of the grenadier guards is marching past the end of the street, banners flying and trumpets sounding, do you not hear or see anything?" "No," replied the philosopher. "I don't believe you!" said the questioner and sat down crossly.

This point illustrates a limitation of a purely philosophical approach to the understanding of memory in particular, and to mind in general, namely its reliance on introspection, the capacity to reflect and report our ongoing thoughts. These are not unimportant, but are not a reliable indication of the way our minds work, for two principal reasons. The first of these, as our example shows, is that people differ in what they appear to experience in a given situation; does memory depend on visual imagery, and if not, why do some of us experience it? Second and even more importantly, we are only consciously aware of a relatively small proportion of the mechanisms underpinning our mental life, and as we will see, the tip of the mental iceberg that is available to conscious awareness is not necessarily a good guide to what lies beneath.

While there are still important issues addressed by the philosophy of mind, it is now generally acknowledged these can best be pursued in collaboration with a scientific approach based on empirical evidence. To return to the question of imagery, as I suspect Ayer knew, in the late 19th century, Sir Francis Galton had asked a number of "eminent men" to reflect on their breakfast table from that morning and describe the vividness of the resulting memory, finding a huge range of responses. What was not known by Galton is that these huge differences are not reflected in how accurate our memories are, suggesting that accuracy depends on some nonconscious process. Could it be that different people have the same experience but just describe it differently? Or do they have different memory systems? Or perhaps they have the same basic systems but have a different way of using them?

So how can we move beyond introspection?

An answer to this started to develop in Germany in the latter half of the 19th century. It was concerned initially with the discipline of *psychophysics*, an attempt to systematically map the relationship between physical stimuli such as brightness and loudness onto their perceived magnitude. Despite success in linking physical stimuli to the psychological experience of participants, capacities such as learning and memory were initially regarded as unsuitable for experimental study. This view was dramatically overturned by a German philosopher Herman Ebbinghaus who conducted an

Ebbinghaus (1850–1909) was the first person to demonstrate that it was possible to study memory experimentally.

intensive series of experiments on himself over a two-year period, showing that it was indeed possible to plot systematic relationships between the conditions of learning and the amount learned. Having published this, the first classic book on the science of memory (Ebbinghaus, 1885), he moved on to study color vision, intelligence, and a range of other questions in the newly developing field of experimental psychology.

So what did Ebbinghaus do? He began by simplifying the experimental situation, attempting to develop material that was devoid of meaning but was verbally learnable and reportable, inventing what has become known as the nonsense syllable, a consonant-vowel-consonant nonword such as *zug pij* and *tev*. He served as his own subject, always holding constant the room in which he learned, the time of day, and the rate of presentation which was rapid, so as to avoid any temptation to attempt to find meaning in the stimuli. Ebbinghaus established some of the basic principles of learning that will be discussed in Chapter 5 and the classic forgetting curve shown in Figure 1.1 that forms the basis of all subsequent work in this area (see Chapter 9).

The Ebbinghaus tradition was subsequently most strongly developed in the US, focusing particularly on the factors and conditions surrounding the important question of how new learning interacted with what was already known. Results were interpreted in terms of associations that were assumed to be formed between stimuli and responses, using a limited range of methods that typically involved remembering lists of nonsense syllables or words (McGeoch & Irion, 1952). This is often referred to as the **verbal learning** approach. It developed from the 1930s to the 1960s, particularly in US mid-Western laboratories, and emphasized the careful mapping of phenomena rather than the ambitious building of grand theories such as that proposed by Clark Hull's general theory of learning based largely on the behavior of rats

KEY TERM

Verbal learning: A term applied to an approach to memory that relies principally on the learning of lists of words and nonsense syllables.

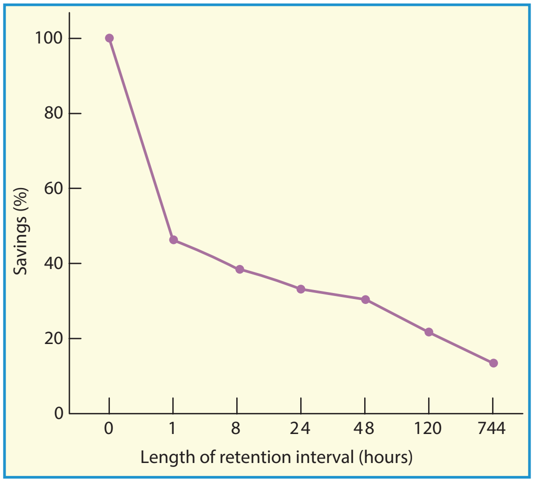

Figure 1.1 Forgetting over time as indexed by reduced savings during relearning. Data from Ebbinghaus (1885).

in mazes which was presented in an elaborate style based directly on that used by Isaac Newton in presenting his classic work, the *Principia*. However the various disputes between such theories appeared to reach deadlock in the late 1950s leading to their general abandonment. This allowed the more staid verbal learning approach, previously disparagingly discounted by its critics as "dust bowl empiricism," to attract a broader range of investigators interested in studying learning and memory. This in turn led to the founding of a new journal, *The Journal of Verbal Learning and Verbal Behavior*, which, when the term "verbal learning" later became unfashionable, became *The Journal of Memory and Language*.

A second development that occurred at this point had its roots in both Europe and North America. In the 1930s, a German approach known as **Gestalt psychology** began attempting to apply ideas developed in the study of perception to the understanding of human memory. Unlike the behaviorist approaches, *Gestalt* psychologists tended to emphasize the importance of internal representations rather than observable stimuli and responses, and to stress the active role of the rememberer. Gestalt psychology suffered badly from Nazi persecution, but enough Gestalt psychologists moved to North America to sow the seeds of an alternative approach to verbal learning; an approach that placed much more emphasis on the activity of the learner in organizing material. This approach was typified by two investigators who had grown up in Europe but had then emigrated and been trained in North America: George Mandler and Endel Tulving.

In Britain, a third approach to memory had developed, based on Frederic Bartlett's (1932) book *Remembering*. Bartlett explicitly rejected the learning of meaningless material as an appropriate way to study memory, using instead complex material such as folk tales from other cultures, reflecting his interest in social psychology and stressing the importance of the rememberer's "effort after meaning." This approach emphasized the study of the memory errors that people made, explaining them in terms of the participants' cultural assumptions about the world. Bartlett proposed that these depended on internal representations that he referred to as **schemas**. His approach differed radically from the Ebbinghaus tradition that influenced the verbal learning approach, but left Bartlett with the problem of how to study these elusive inner representations of the world.

A possible answer to this problem evolved gradually during World War II with the development of computers. Mathematicians such as Weiner (1950) in the US, and physiologists such as Gray Walter (1953) in the UK described machines that were able to demonstrate a degree of control that resembled purposive behavior. During the 1940s, a Scottish psychologist, Kenneth Craik (1943), working with Bartlett in Cambridge produced a brief but influential book entitled *The Nature of Explanation*. Here he proposed the idea of representing theories as **models**, and using the computer to develop such models. He carried out what were probably the first psychological experiments based on this idea, using analog computers (digital computers were still being invented) and applying his computer-based theoretical model to the practical problem of gun-aiming in tanks. Tragically, in 1945 he was killed in a traffic accident while still a young man.

Fortunately, the new approach to psychology, based on the computer metaphor, was being taken up by a range of young investigators, and in the years following the war, this information-processing approach to psychology became increasingly influential. Two books were particularly important. Donald

KEY TERM

Gestalt psychology: An approach to psychology that was strong in Germany in the 1930s and that attempted to use perceptual principles to understand memory and reasoning.

Schema: Proposed by Bartlett to explain how our knowledge of the world is structured and influences the way in which new information is stored and subsequently recalled.

Model: A method of expressing a theory more precisely, allowing predictions to be made and tested.

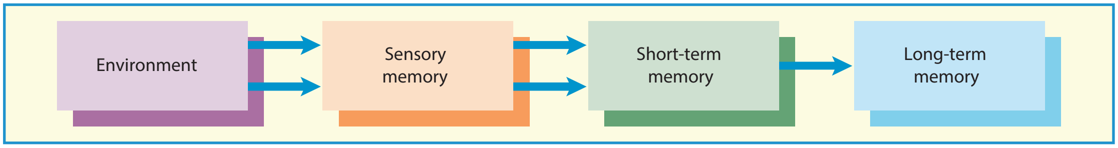

Figure 1.2 An information-processing approach to memory. Information flows from the environment through sensory storage and short-term storage to long-term memory.

Broadbent's *Perception and Communication* (1958) developed and applied Craik's seminal ideas to a range of work carried out at the Medical Research Council Applied Psychology Unit in Cambridge, England, much of it stimulated by practical problems originating during the war. Some nine years later, this growing field was then brilliantly synthesized and summarized by Ulric Neisser (1967) in a book whose title provided a name for this burgeoning field: *Cognitive Psychology*.

Using the digital computer as an analogy, human memory could be regarded as comprising one or more storage systems. Any memory system—whether physical, electronic, or human—requires three things, the capacity to *encode*, or enter information into the system, the capacity to *store* it, and—subsequently—the capacity to find and *retrieve* it. However, although these three stages serve different functions, they interact: The method of registering material or encoding determines what and how the information is stored, which in turn will limit what can subsequently be retrieved. Consider a simple physical memory device, a shopping list. If it is to work, you need to write legibly in a language the recipient shopper understands. If it were to get wet, the ink would blur (impaired storage) making it less distinct and harder to read (retrieval). Retrieval would be harder if your handwriting was poor (an encoding-retrieval interaction), and if the writing was smudged (a storage-retrieval interaction). The situation is further complicated by the discovery that our memories comprise not one, but several interrelated memory systems.

HOW MANY KINDS OF MEMORY?

As the influence of the cognitive approach to psychology grew, the balance of opinion moved from the assumption of a single memory system based on stimulus–response associations towards the idea that two, three, or perhaps more memory systems were involved. Figure 1.2 shows the broad view that came to be widely accepted during the 1960s. It assumed that information comes in from the environment and is first processed by a series of sensory memory systems, which could be best regarded as providing an interface between perception and memory. Information is then assumed to be passed on to a temporary short-term memory system, before being registered in long-term memory. A particularly influential version of this model was proposed by Atkinson and Shiffrin (1968). It was dubbed the **modal model** because it was representative of many similar models of the operation of human memory that were proposed at the time. As we shall see, a number of the assumptions underlying this model were subsequently questioned, causing it to be further elaborated.

The question of how many kinds of memory remains controversial; some theorists object to the very concept of a memory *store* as too static, arguing instead that we should be concerned with *processes* (e.g., Nairne, 1990, 2002; Neath & Surprenant, 2003). They point to similarities across a

KEY TERM

Modal model: A term applied to the model of memory developed by Atkinson and Shiffrin (1968).

range of very different memory tasks and suggest that these imply common processes, and hence a unitary memory system. Our own view is that we need to think in terms of both structures such as stores and the processes that operate on them, just as an analysis of the brain requires the contribution of both static anatomical features and a more dynamic concern with physiology. We should certainly look for similarities across domains in the way that these systems perform, but the presence of common features should not encourage us to ignore the differences.

Fortunately, regardless of the question of whether one emphasizes similarities or differences, the broad picture remains the same. In what follows, we ourselves use the distinctions between types of memory as a way of organizing and structuring our knowledge of human memory. As discussed below, we assume separate sensory, short-term, and long-term memory systems, each of which can be subdivided into separate components. We do not, however, assume the simple flow of information from the environment into long-term memory that is suggested in Figure 1.2, as there is abundant evidence that information flows in both directions. For example, our knowledge of the world, stored in long-term memory, can influence our focus of attention, which will then determine what is fed into the sensory memory systems, how it is processed, whether as familiar objects or as meaningless shapes, and hence how well it is subsequently remembered. This will become even more important with the perception of complex active scenes. Thus a keen football fan watching a game will see and remember particular plays that her less knowledgeable companion will miss.

We begin with a brief account of sensory memory. This was an area of considerable activity during the 1960s and provides a good illustration of the general principles of encoding, storage, and retrieval. However, given that it relates more to perception than memory, it will not be covered in the remainder of the book. Our outline continues with introductory accounts of short-term and working memory, before moving to a preliminary survey of long-term memory.

SENSORY MEMORY

If you wave your hand while holding a sparkler in a dark room, it leaves a trail, which rapidly fades. The fact that the image persists long enough to draw an apparent line suggests that it is being stored in some way, and the fact that the line rapidly fades implies some simple form of forgetting. This phenomenon forms the basis for movies; a sequence of static images is presented rapidly, with blank intervals in between, but is perceived as a continuous moving image. This occurs because the perceptual system stores the visual information long enough to bridge the gap between the static images, integrating each one with the next, very slightly different, image.

Neisser (1967) referred to this brief visual memory system as iconic memory, referring to its auditory counterpart as "echoic memory." In the early 1960s, a number of investigators at Bell Laboratories in the US used the new information-processing approach to analyze this fleeting visual memory system (Averbach & Sperling, 1961; Sperling, 1960, 1963). Sperling (1960) briefly presented a visual array of 12 letters in three rows of four, and then asked for recall (Figure 1.3). People could typically remember four or five items correctly. If you try this task, however, you will have the sensation that you have seen more than four or five, but that they have gone before you can report them. One way of avoiding the problem of forgetting during reporting is to present the same array but ask for only one row to be reported, but not telling the participant in advance which row will be tested, hence requiring the whole set to be encoded. The row to be recalled is then specified by presenting a tone; a high tone for the top line, a medium tone for line two, and a low tone for

KEY TERM

Sensory memory: A term applied to the brief storage of information within a specific modality.

Iconic memory: A term applied to the brief storage of visual information.

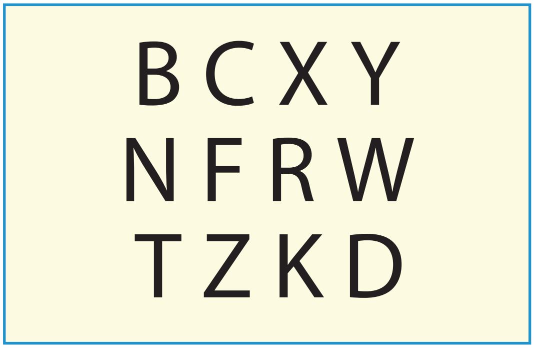

Figure 1.3 Stimulus array used by Sperling. Although 12 letters were presented, participants only had to recall one row, that cued by a high, medium, or low tone.

line three. As Sperling did not tell the participant in advance which line would be cued, the report could be treated as representative of the whole array; multiplying the score by three will thus give an estimate of the total number of letters stored. However, as shown in Figure 1.4, amount recalled depends on when the recall tone is presented. When recall is tested immediately, it should provide an estimate of the total capacity of the memory store, with the fall-off in performance as the tone is delayed representing the loss of information. Note that Figure 1.4 shows two curves, one with a bright field before and after the letters, and the other with the letters preceded and followed by a dark visual field. A subsequent experiment (Sperling, 1963) found that the brighter the light during the interval, the poorer the performance, suggesting that the light is interfering with the memory trace in some way, a process known as **masking**.

Later work by Michael Turvey (1973) investigated two separate types of masking operating at different stages. The first of these involves *brightness masking*, with the degree of masking increasing when the mask becomes brighter, or is presented closer in time to the stimulus. This effect only occurs if the mask and the stimulus are presented to the same eye, suggesting that it is operating at a peripheral retinal level. If you were a subject in such an experiment, this type of masking would give rise to experiencing a composite of target and mask, with the brighter the mask the less distinct the target.

KEY TERM

Masking: A process by which the perception and/or storage of a stimulus is influenced by events occurring immediately before presentation (forward masking) or more commonly after (backward masking).

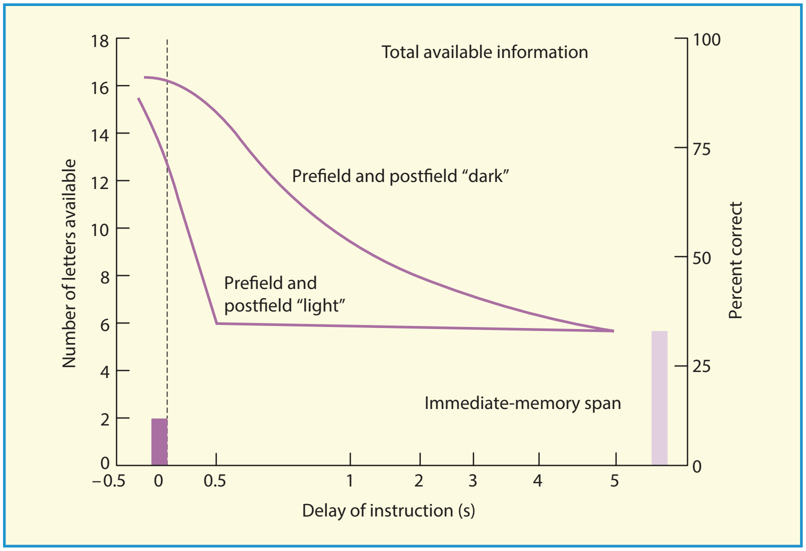

Figure 1.4 Estimated number of letters available using the partial report method, as a function of recall delay. From Sperling (1963). Copyright © 1963 by The Human Factors Society and Ergonomics Society Inc. Reprinted by permission of Sage Publications.

This is distinct from *pattern masking*, the second type studied which occurs when targets are followed by a mask comprising broadly similar features to the target, for example jumbled fragments of letters. This type of mask operates even when the target is presented to one eye and the mask to the other. This suggests that it influences a later stage of visual processing that occurs after information from the two eyes has been combined into a single percept. It is relatively insensitive to brightness and subjectively feels as if a clear image has been disrupted before the information could adequately be read off from it.

What function does iconic memory serve other than that of keeping psychologists busy, or as Haber concluded in desperation, reading at night in a thunderstorm? The answer is that its function is probably indirect, forming part of the process of perceiving the world. As we scan the visual world, stimuli of huge complexity will fall on our retina, comprising far more information than it is useful for us to process and store. It seems likely that iconic memory represents two early stages of a process whereby information is read off from the retina, and some of it then fed through to a more durable short-term visual store. It is this that allows us to build up a coherent representation of the visual world and that allows a movie to be perceived, not a series of static frames with gaps in between, but as a continuous and realistic visual experience. The early stages of iconic memory are probably best regarded as aspects of perception, while the subsequent more stable stage will be discussed in the chapter on short-term memory.

The auditory system also involves a brief sensory memory component that Neisser named **echoic memory**. If you are asked to remember a long telephone number, then your pattern of errors will differ depending on whether the number is heard or read. With visual presentation, the likelihood of an

KEY TERM

Echoic memory: A term sometimes applied to auditory sensory memory.

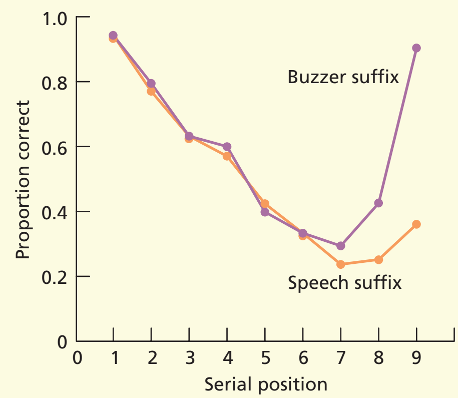

Figure 1.5 Serial recall of a nine-item list when an additional item, the suffix, is either the spoken word zero or a sound made by a buzzer. From Crowder (1972). © 1972 Massachusetts Institute of Technology, by permission of The MIT Press.

error increases systematically from the beginning to the end of the sequence, whereas, as shown in Figure 1.5, with auditory presentation the last one or two items are much more likely to be correct than are items in the middle of the list (Murdock, 1967). This recency advantage can be removed by interposing another spoken item between presentation and recall, even when this item itself does not need to be processed, and is always the same, for example, the instruction "recall." In an extensive series of experiments, Crowder and Morton (1969; Crowder, 1971) showed that the nature of this suffix is critical. A visual or nonspeech-like auditory suffix, such as a buzzer, does not disrupt performance, whereas a spoken suffix does, regardless of its meaning.

Crowder and Morton postulated what they term a precategorical acoustic store as the basis for the auditory recency effect. However, the question of whether the process responsible for the enhanced auditory recency effect is better regarded as a form of memory or an aspect of perception remains controversial (Jones, Hughes, & Macken, 2006; but see also Baddeley & Larsen, 2007). Regardless of its interpretation, the auditory recency component is sufficiently large and robust to play a potentially significant role in studies of verbal short-term memory, and has even been proposed as an alternative to more conventional views of performance on short-term verbal memory tasks (Jones et al., 2006). We will return to this issue when discussing short-term memory. In the meantime, it seems likely that an adequate explanation of echoic memory will need to be fully integrated with a broader theory of speech perception.

SHORT-TERM AND WORKING MEMORY

As this topic, and that of long-term memory, forms a major part of the book, for present purposes we will limit ourselves to a very brief outline. We use the term short-term memory (STM) in a theory-neutral way to refer to the temporary storage of small amounts of material over brief delays. This leaves open the question of how this storage is achieved. In most, if not all situations there is likely to be a contribution to performance from long-term memory that will need to be taken into account in evaluating the role of any more temporary storage systems. Much of the work in this area has used verbal material, and there is no doubt that even when the stimuli are not verbal, people will often use verbal rehearsal to help maintain their level of performance over a brief delay (see Chapter 4). It is important to bear in mind, however, that STM is not limited to verbal material, and has been studied extensively for visual and spatial information, though much less extensively for smell and touch.

The concept of working memory is based on the assumption that a system exists for the temporary maintenance and manipulation of information, and that this is helpful in performing many complex tasks. A number of different models of working memory have been proposed, with the nature and emphasis of each model tending to depend on the particular area of interest of the theorist, and their theoretical style. However, most assume that working memory acts as a form of mental workspace, providing a basis for thought. It is usually assumed to be linked to attention, and to be able to draw on other resources within short-term and long-term memory (Miyake & Shah, 1999). By no means all approaches, however, emphasize the role of memory rather than attention. One approach that does so is the multicomponent model proposed originally by Baddeley and Hitch in 1974 as a means of linking research on the psychology and neuropsychology of STM to its functional role in performing important cognitive activities such as reasoning, comprehension, and learning. This approach has continued to prove productive for over 30 years (Baddeley, 2007) and is the principal focus of Chapter 4.

LONG-TERM MEMORY

We shall use the classification of long-term memory proposed by Squire (1992). As shown in Figure 1.6, this classification makes a broad distinction between explicit or declarative memory and implicit or nondeclarative memory. Explicit memory refers to situations that we would generally think of as involving memory, both for specific *events*, such as meeting a friend unexpectedly on

KEY TERM

Short-term memory (STM): A term applied to the retention of small amounts of material over periods of a few seconds.

Working memory: A memory system that underpins our capacity to "keep things in mind" when performing complex tasks.

Long-term memory: A system or systems assumed to underpin the capacity to store information over long periods of time.

Explicit/declarative memory: Memory that is open to intentional retrieval, whether based on recollecting personal events (episodic memory) or facts (semantic memory).

Implicit/nondeclarative memory: Retrieval of information from long-term memory through performance rather than explicit conscious recall or recognition.

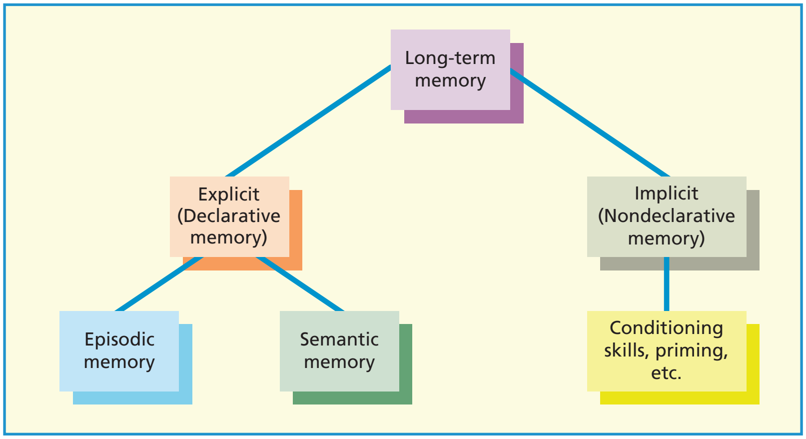

Figure 1.6 Components of long-term memory as proposed by Squire (1992).

holiday last year, and remembering *facts* or information about the world, for example the meaning of the word *testify* or the color of a ripe banana. Implicit memory refers to situations in which some form of learning has occurred, but which is reflected in *performance* rather than through overt remembering, riding a bicycle for example or reading a friend's handwriting more easily because we have encountered it frequently in the past. We will briefly discuss these in turn, leaving a full exploration to subsequent chapters.

Explicit memory

As Figure 1.6 shows, this can be divided into two categories, semantic and episodic memory. During the 1960s, computer scientists attempting to achieve automatic language processing discovered that their computer programs needed to have built into them some kind of knowledge of the world, which could represent the meaning of the words being processed. This led psychologists to attempt to study the way in which humans store such semantic information. At a conference convened to discuss these new developments, a Canadian psychologist Endel Tulving (1972) proposed a distinction that was immediately adopted and has been used extensively ever since, that between *semantic* and *episodic* memory. Semantic memory refers to knowledge of the world. It goes beyond simply knowing the meaning of words and extends to sensory attributes such as the color of a lemon or the taste of an apple. It also includes general knowledge of how society works, what to do when you enter a restaurant, or how to book a theater seat. It is inherently general in nature, although it can in principle be acquired on a single occasion. If you heard that an old friend had died, this would be likely to

KEY TERM

Semantic memory: A system that is assumed to store accumulative knowledge of the world.

Episodic memory: A system that is assumed to underpin the capacity to remember specific events.

Semantic memory goes beyond the meaning of words, and extends to sensory attributes such as taste and color; and to general knowledge of how society works, such as how to behave in a supermarket.

become part of your general knowledge of that person, hence part of your semantic memory, although you might well forget where or when you had heard this.

If you subsequently recall the particular occasion when and where you had learned this sad news, then this would be an instance of *episodic memory*, which underpins the capacity to remember specific single episodes or events. Hence, a given event can be registered in both types of memory. Tulving himself (2002) now limits the use of the term "episodic memory" to situations in which you actually re-experience some aspect of the original episode, for example remembering how surprised you were that your informant knew your old friend. Tulving refers to this capacity as **mental time travel** and emphasizes its value, both in allowing us to recollect and "relive" individual events, and to use that information for planning a future action, for example sending a letter of condolence. It is this capacity to acquire and retrieve memories for particular events that tends to be most severely disrupted in amnesic patients, and it is this deficit that has made Clive Wearing's life so unbearably difficult.

How are semantic and episodic memory related? One possibility is that semantic memory is simply the residue of many episodes. For example, I know that Madrid is the capital of Spain, not only because I was told it at school but also because I have encountered this fact in countless news-reels and had it reinforced by visiting Madrid. Consistent with this assumed role of episodic memory in forming semantic memory is the fact that most amnesic patients have difficulty in building up new semantic knowledge. They typically would not know the name of the current President of the United States of America, or what year it is, or which teams were doing well in their favorite sport. Whether this means that semantic and episodic memory involve separate storage systems (Tulving, 2002), or whether they reflect separate retrieval routes to a common store as I have recently suggested (Baddeley, in press) remains to be decided.

Implicit memory

Amnesic patients thus tend to show not only grossly disturbed episodic memory, but also a greatly impaired capacity to add to their store of knowledge of the world. There are however a number of situations in which they do appear to learn at a normal rate, and the study of these preserved capacities has had an important influence on the development of the concept of implicit or nondeclarative memory.

One preserved form of learning is simple **classical conditioning**. If a tone is followed by a brief puff of air to the eye, amnesic patients will learn to blink in anticipation (Weiskrantz & Warrington, 1979). Despite learning at a normal rate, they do not remember the experience and cannot explain the function of the nozzle that delivers the air puff to their eye. Amnesic patients can also learn motor skills, such as improving with practice the capacity to keep a stylus in contact with a moving spot of light (Brooks & Baddeley, 1976). Warrington and Weiskrantz (1968) demonstrated that word learning was also preserved in densely amnesic patients under certain conditions. They presented their patients with a list of unrelated words and then tested for retention in a number of different ways. When asked to recall the words or recognize which of the subsequent sequence of words had already been presented, the patients performed very poorly. However, when the nature of the test was changed to one in which the task was to "guess" a word when given the first few letters, both patients and normal participants were likely to "guess" a word that had been seen earlier. For example, a patient who had

KEY TERM

Mental time travel: A term coined by Tulving to emphasize the way in which episodic memory allows us to relive the past and use this information to imagine the future.

Classical conditioning: A learning procedure whereby a neutral stimulus (e.g., a bell) that is paired repeatedly with a response-evoking stimulus (e.g., meat powder), will come to evoke that response (salivation).

been shown the word "bring" and was later given the letters "BR–" would be just as likely as control participants to guess "bring" rather than "bread," but would not remember having just seen that word. Patients could take full advantage of their prior experience, despite failing to remember that they had even been shown any words earlier, indicating that *something* had been stored. As we shall see, this phenomenon, known as **priming**, is found in a range of perceptual tasks, both visual and auditory, and can also be found in the progressive improvement in more complex activities such as reading mirror writing (Cohen & Squire, 1980) or assembling a jigsaw puzzle (Brooks & Baddeley, 1976).

Given that these are all examples of implicit learning and memory, do they all reflect a single memory system? While attempts have been made to account for them all in terms of a single system (see Neath & Surprenant, 2003), our own view is that although they have features in common, they represent a range of different learning systems using different parts of the brain that have evolved for different purposes. They seem to represent a tendency for evolution to develop similar ways of addressing problems across different systems.

MEMORY: BEYOND THE LABORATORY

We have so far discussed the question of how to develop a theoretical understanding of human memory: How it encodes, stores, and retrieves information. However, if our theory is to be useful as well as informative, then it needs to be applicable beyond the confines of the laboratory, to tell about how our memories will work in the world. It must aim to extend beyond the student population, on which much of the research is based, and tell us about how memory functions in children and the elderly, across different cultures, and in health and disease.

It is of course much more difficult to run tightly controlled experiments outside the laboratory, with the result that most of the theoretically focused studies that inform the initial chapters are laboratory based. Some investigators argue that we should confine our research to the laboratory, extending it only when we have a thorough understanding of memory. Others have followed Bartlett in suggesting that this is likely to lead to the neglect of important aspects of memory. In response to this rather conservative view, a group of psychologists in South Wales enthusiastically convened an international conference concerned with practical aspects of memory. It was a great success, with people coming from all over the world to talk about their research on topics ranging from memory for medical information to sex differences in facial memory, and from expert calculators to brain-damaged patients (Gruneberg, Morris, & Sykes, 1978).

Ulric Neisser was invited to give the opening address. In it, he lamented the laboratory-based tradition declaring that "If X is an interesting or socially significant aspect of memory, then psychologists have hardly ever studied X!" (Neisser, 1978, p. 4). He was in fact preaching to an enthusiastic audience of the converted, whose work presented over the next few days was already refuting his claim. However, his address was less well received in other quarters, resulting in a paper complaining of "the bankruptcy of everyday memory" (Banaji & Crowder, 1989). This led to a lively, although rather unfruitful, controversy, given that it was based on the false assumption that psychologists should limit their research to *either* the laboratory *or* the world beyond. Both approaches are valuable. It is certainly easier to develop and test our theories under controlled laboratory conditions, but if they tell us little or nothing about the way in which memory works in the world outside, they are of distinctly limited value.

KEY TERM

Priming: The process whereby presentation of an item influences the processing of a subsequent item, either making it easier to process (positive priming) or more difficult (negative priming).

In Medieval times, accurate and precise articulation of the words of the church liturgy was more important than the sound of the music, with errors taken very seriously. The demon Titivillus was believed to take time off from his other task of inducing errors in written manuscripts to collect such omissions and slips of the tongue. Each day a thousand bags of such lapses would be conveyed to his master Satan, written in a book of errors and used against the unfortunate cleric on the Day of Judgment. It appears that in due course the level of accuracy improved to a point at which Titivillus was driven to filling his sack with idle gossip from the congregation, a rather menial task for a respectable demon (Zieman, 2008).

In general, attempts to generalize our theories have worked well, and have in turn enriched theory. One important application of theory is to the memory performance of particular groups such as children, the elderly, and patients with memory problems. As we will see, these not only demonstrate the robustness and usefulness of cognitive theories, but have also provided ways of testing and enriching the theory. A good case in point is the study of patients with a very dense but pure amnesia, which has told us about the everyday importance of episodic memory, has helped develop tests and rehabilitation techniques for clinical neuropsychologists, and has, at the same time, had a major impact on our theories of memory.

A second major benefit from moving beyond the laboratory comes from a realization that certain very important aspects of memory were not being directly covered by existing theories. Some of these have led to important new theoretical developments. This is the case with the study of semantic memory which, as mentioned earlier, was initially prompted by the attempt of computer scientists to develop programs that could understand language (Collins & Quillian, 1969). Another area of very active research that was driven by a practical need is that of eyewitness testimony, where it became clear that the failures of the judiciary to understand the limitations of human memory were often leading to potentially very serious miscarriages of justice (Loftus, 1979). Other areas have developed as a result of identifying practical problems that have failed to be addressed by theory. A good example of this is prospective memory, remembering to do things. This use of memory is of great practical importance, but for many years was neglected because it reflects a complex interaction between attention and memory. These broader topics are covered in the latter part of the book, which will illustrate the now widely accepted view that theoretical and practical approaches to memory are allies and not rivals.

The contribution of neuroscience

Both the Ebbinghaus and Bartlett approaches to the study of memory were based on the psychological study of memory performance in normal individuals. In recent years, however, this approach has increasingly been enriched by data from neuroscience, looking at the contribution of the brain to our capacity to learn and remember. Throughout this book, you will come across cases in which the study of memory disorders in patients has thrown light on the normal functioning of human memory. In particular, the problems faced by patients with memory problems can often tell us about the function that our memories serve, and how they can be further investigated. Recent years have seen a rapid development of methods that allow the neuroscientist to observe and record the operation of the brain in healthy people both at rest and while performing complex activities, including those involved in learning and remembering. These will be discussed in the next chapter.

SUMMARY

- Although we complain about our memories, they are remarkably efficient and flexible in storing the information we need and discarding what is less important.
- Many of our memory lapses result from this important need to forget nonessentials, if we are to remember efficiently.
- The study of memory began with Ebbinghaus, who greatly simplified the experimental situation, creating a carefully constrained approach that continued in North America into the 20th century.
- Alternative traditions developed in Germany, where the study of perception influenced the way in which Gestalt psychologists thought about memory, and in Britain, where Bartlett used a richer and more open approach to memory.
- During the 1950s and 1960s, these ideas, influenced further by the development of the computer, resulted in an approach that became known as cognitive psychology.
- In the case of memory, this emphasized the need to distinguish between encoding or input into memory, memory storage, and memory retrieval, and to the proposal to divide memory into three broad types, sensory memory, short-term memory, and long-term memory.
- The information-processing model is very well illustrated in Sperling's model of visual sensory memory, in which the various stages were ingeniously separated and analyzed.
- These were assumed to lead into a temporary *short-term* or *working memory*. This was initially thought to be largely verbal in nature but other modalities were subsequently shown to be capable of temporary storage.
- The short-term memory system was assumed to feed information into and out of long-term memory.
- Long-term memory was further subdivided into *explicit* or declarative memory, and *implicit* or nondeclarative memory.
- Explicit memory was further divided into two types: The capacity to recollect individual experiences, allowing "mental time travel," became known as *episodic memory*, whereas our stored knowledge of the world was termed *semantic memory*.
- A range of implicit or nondeclarative learning and memory systems were identified, including classical conditioning, the acquisition of motor skills, and various types of priming.
- An important development in recent years has been the increased interest in extending theory beyond the laboratory.
- However, this has led to controversy—it is clear that we need the laboratory to refine and develop our theories, but that we also need to move outside the laboratory to investigate their generality and practical importance.

POINTS FOR DISCUSSION

1 What are the strengths and weaknesses of the approach to memory taken by Ebbinghaus and Bartlett?
2 How did the cognitive approach to memory build on these foundations?
3 Do we need to assume more than one kind of memory? If so, why?

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Rabbitt, P. (2008). *Inside psychology: A science over 50 years*. New York: Oxford University Press. A series of personal views of the recent history of psychology from individuals who have been involved in a wide range of areas, including memory.

Roediger, H. L., Dudai, Y., & Fitzpatrick, S. M. (2007). *Science of memory: Concepts*. Oxford: Oxford University Press. The proceedings of a conference at which leading figures in learning and memory were invited to summarize their interpretation of the basic concepts underlying the field, and to present their own views. Because available space was limited, this provides a very economical way of accessing current expert views concerning both the psychology and neuroscience of learning and memory.

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Contents

CHAPTER 2

MEMORY AND THE BRAIN

Alan Baddeley

While our main focus will be on the psychology of memory, as knowledge of the field develops, it becomes increasingly possible to link psychological concepts, methods, and findings to efforts towards understanding the biological basis of memory (see Box 2.1). Note that this is not a case of simple reductionism; knowing that a particular area of the brain is involved with a given memory function, for example, does not constitute an explanation, but does provide an additional source of evidence that may be useful in further developing a psychological explanation, in addition of course to the separate but related issue of understanding how the brain works. We will be referring to such evidence throughout the following chapters, and for that reason it is important to understand something of the methods that are currently used to study the relationship between memory and the brain. We will begin with one of the most established methods, neuropsychology, going on to discuss the rapidly developing field of brain imaging, concluding with a brief account of the more basic biological approaches that go beyond systems neuroscience to study the neurobiological basis of memory, and of its potential genetic control, areas that have so far had relatively little impact at the psychological level, but which may in the future prove to be of considerable importance.

NEUROPSYCHOLOGICAL APPROACHES

Patients who suffer brain damage often have memory problems, with the nature of the problem often being associated to a greater or lesser degree with the cause and anatomical location of the damage (see Chapter 16).

Group studies: This approach involves selecting patients whose damage is broadly associated with a specific disease or cause, for example the **traumatic brain injury (TBI)** that might result from a blow on the head in a traffic accident. This approach is clinically important in providing an overview of the condition necessary for treating patients and in prognosis for recovery, but may be difficult to interpret theoretically. Typically the more severe the accident, for example, the longer the period of unconsciousness or coma, the greater memory disturbance and the poorer the chance of good recovery. However, in addition to memory deficits such patients will typically have other problems, particularly

KEY TERM

Traumatic brain injury (TBI): Caused by a blow or jolt to the head, or by a penetrating head injury. Normal brain function is disrupted. Severity ranges from "mild" (brief change in mental status or consciousness) to "severe" (extended period of unconsciousness or amnesia after the injury).

Box 2.1 The biological basis of memory

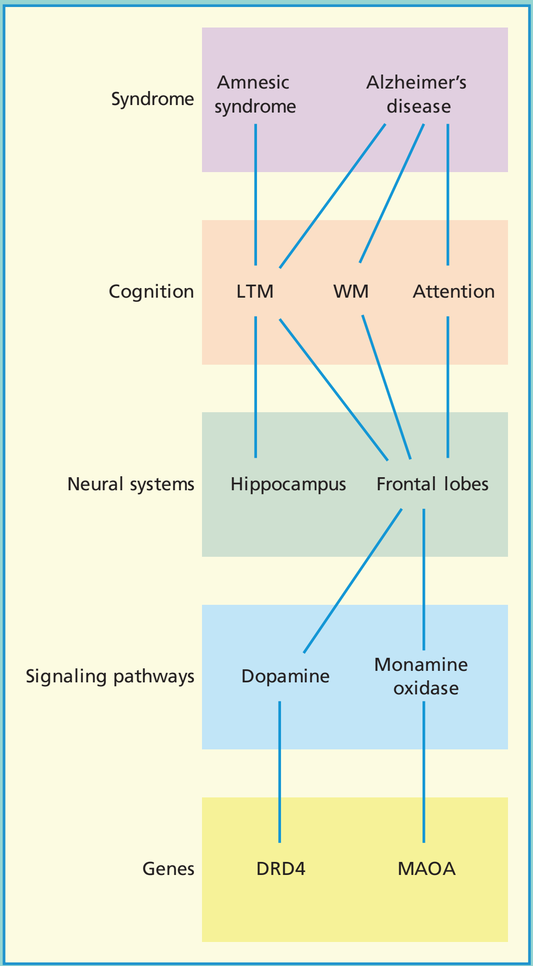


Figure 2.1

The psychology of memory and its dysfunction can be studied at a range of levels. These include its reflection in memory disorders which can then be mapped onto cognitive psychology. This in turn can be analyzed in terms of the neural systems underpinning cognition, together with their representation in different areas of the brain. Such systems themselves depend on neurochemically modulated signaling pathways that transmit information between the systems in ways that are themselves dependent on activity at the gene level. Adjacent levels of explanation tend to interact. Our own focus is at the cognitive level, but evidence from both syndromes and neural systems will be used in developing and evaluating both theory and practice.

Based on Poldrack et al. (2011).

attentional, making it difficult to separate the memory deficits from other factors. Hence, although TBI is an area of considerable practical importance, it does not lead to clear theoretical conclusions about the nature of memory.

More informative are diseases such as alcoholic Korsakoff syndrome, a result of drinking too much and eating too little, in which memory deficits are particularly prominent, while other cognitive functions can be relatively preserved. Even here, however, most patients will show other deficits including subtle deficits of attentional control,

KEY TERM

Alcoholic Korsakoff syndrome: Patients have difficulty learning new information, although events from the past are recalled. There is a tendency to invent material to fill memory blanks. Most common cause is alcoholism, especially when this has resulted in a deficiency of vitamin B1.

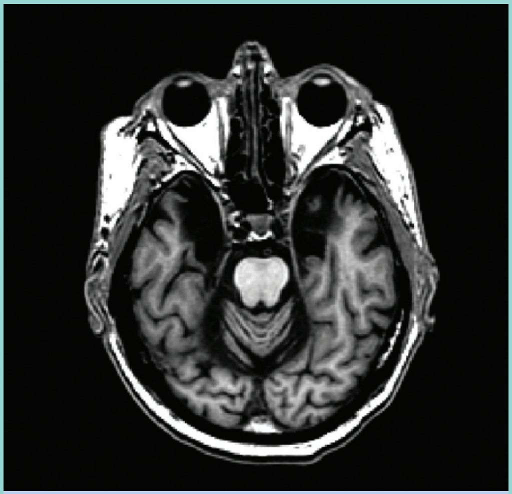
again making clear theoretical interpretation difficult; does the patient have a problem of memory, or attention, or both? Most informative are the rare cases in which the brain damage appears to disrupt a single isolated function such as episodic memory, while intelligence, attention, perception, and language capacities are all preserved. The classic case of amnesia is that of Henry Molaison, known by his initials HM.

Box 2.2 HM

The most theoretically influential neuropsychological case ever was that of HM, a young man with temporal lobe epilepsy. In a successful attempt to reduce his seizures, areas of his brain associated with the left and right hippocampus were surgically removed. Unfortunately, HM then became densely amnesic. His capacity to acquire new information was severely limited, as was the case with Clive Wearing discussed earlier. Unlike Clive, however, HM's deficits were principally limited to episodic long-term memory. His digit span was normal, his intelligence was unimpaired, as was his language capacity but his LTM was grossly disrupted. He was unable to remember experiences for more than a few minutes, performed very badly on standard visual and verbal memory tests, failed to learn the names or faces of new people or indeed new presidents and to learn where things were kept when he moved to a new home. HM's case had a major influence on two aspects of memory. Neurosurgically he demonstrated the practical importance of anatomical location, stimulating extensive later work on brain–behavior relationship. Psychologically his case supported a separation of functions, between memory and intelligence and between long- and short-term memory.

When Henry died in 2008 at the age of 82, his importance was recognized worldwide by extensive obituaries, together with a book-length account of his life and its contributions to the science of memory (Corkin, 2013).

Henry Molaison, aged 60, at MIT in 1986. As a patient, Henry Molaison (HM) made a major contribution to our understanding of memory. Photograph and copyright: Jenni Ogden, author of *Trouble In Mind: Stories from a Neuropsychologist's Casebook*. New York: Oxford University Press, 2012.



MRI images taken in 1992 of HM's brain. The light gray areas represent preserved brain structure and the dark areas an absence of brain tissue.

HM's case was important in demonstrating that episodic LTM is separable from other cognitive capacities, including STM (Corkin, 2013). Such separation is known as a *dissociation* since the specified deficit is separate or dissociated from deficits in other cognitive functions. As such it is considerably more theoretically powerful than a simple correlation whereby a deficit may just be a general consequence of degree of brain damage. Such rare single cases are informative, but need subsequently to be supported by other similar cases, and by coherence with what we already know of normal memory, before strong theoretical conclusions can be drawn. Such support rapidly accumulated in the case for HM (e.g., Baddeley & Warrington, 1970), but even so there is always a nagging fear that perhaps those tests that are impaired are simply harder or more open to disruption than those preserved. Perhaps preserved tasks such as digit span involving hearing and repeating back a sequence of numbers, are simply easier than learning word lists?

To guard against this it is valuable to have a second type of patient showing exactly the opposite pattern, providing what is known as a **double dissociation**. In the case of the amnesic syndrome, this was provided by the discovery of a class of patient who had apparently normal LTM together with grossly disrupted STM (Shallice & Warrington, 1970). Such patients did not appear to be amnesic and could learn lists of words, but had a memory span of two rather than six digits. This pattern could not easily be explained in terms of the greater difficulty or vulnerability of one of the types of task. Even a double dissociation is not a perfect design, however, since it is possible that more than two systems are involved.

As we shall see, such single cases have been extremely important in developing memory theory. They are however a very limited resource, for two reasons. First, because they are rare; most brain damage affects more than one system producing complex and variable deficits. The second problem concerns the increasing complexity of the models of memory that have emerged as study has advanced. While a double dissociation between two systems is desirable and possible, a three-component explanation would logically require a triple dissociation, and a four-component explanation a quadruple dissociation, becoming quite impracticable. At this point it is necessary to rely on a method known as *converging operations*. This involves carrying out a whole series of experiments using different methods and different participant groups, all focused on the same theoretical question. The hope is that although each single experiment is likely to be open to interpretation in more than one way, only one explanation will be able to explain all the results. This is the approach taken to a subsystem such as the phonological loop in working memory discussed in Chapter 4.

Neuropsychology has a further limitation. It requires access to patients, by no means easily achieved in the UK at least. It then needs the skills of a neuropsychologist with a keen eye for theoretically interesting patients, together with access to the experimental and conceptual tools necessary to bring out the significance of the findings. The substantial growth in the number of studies on memory and the brain in recent years has therefore not come principally from the study of such rare patients, but from the development of methods of studying the intact brains of healthy people.

KEY TERM

Double dissociation: A term particularly used in neuropsychology when two patient groups show opposite patterns of deficit, e.g., normal STM and impaired LTM, versus normal LTM and impaired STM.

OBSERVING THE BRAIN

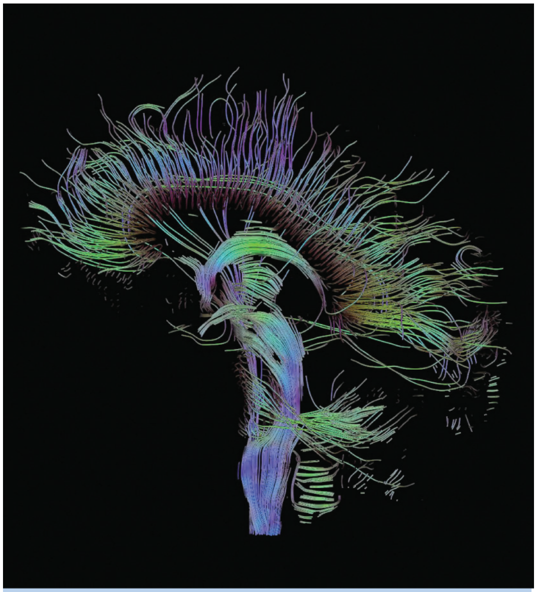
Structural imaging

For many centuries, our knowledge of the structure of the brain was based on post-mortem evidence. It became possible to observe the structure of living patients with the development of the X-ray based technique known as *computerised tomography* (CT). This involves rotating an X-ray tube around the patient's head, providing multiple viewpoints of the brain which are then fed into a computer that creates a three-dimensional representation of the person's brain. This method is still used clinically, but for research purposes it has largely been replaced by **magnetic resonance imaging (MRI)**.

MRI involves placing the person's head in a strong magnetic field. The scanner emits radio waves in a series of brief pulses of different frequency. These are absorbed by the brain, which, when the field is turned off, release the absorbed energy. The absorption characteristics of the brain's gray matter (neuronal cell bodies), differ between white matter (axons linking different brain areas) and cerebro-spinal fluid which fills the ventricle. These comprise hollow chambers in the brain that carry away waste metabolites and also provide protective cushioning for the brain. MRI allows a three-dimensional image to be created that differentiates these aspects of brain structure. The spatial resolution of the resulting image depends upon the strength of the magnet. A typical clinical scanner would have a field strength of 3 Tesla, although scanners with field strengths of up to 7 Tesla are beginning to be available, allowing much finer spatial resolution.

MRI has the advantage over CT in that it does not involve radiation, and gives much more precise images. By varying the frequency of the radio pulse, MRI can be used to emphasise different aspects of brain structure, for example gray matter versus white matter. An example from the brain of patient HM is shown in Box 2.2.

An increasingly important aspect of MRI is the technique known as *diffusion tensor imaging* (DTI). This takes advantage of the fact that the myelin sheaths that surround the white matter fiber tracts connecting different areas of the brain are relatively fatty, causing the water within to flow along that fiber. This approach, sometimes known at *tractography*, allows the mapping of the important white matter bundles that transfer information from one area of the brain to another, allowing the different areas to coordinate functions across the brain.



Visualization of a DTI measurement of a human brain. Depicted are reconstructed fiber tracts that run through the mid-sagittal plane.

KEY TERM

Magnetic resonance imaging (MRI): A method of brain imaging that relies on detecting changes induced by a powerful magnetic field.

Functional imaging: Observing the working brain

While imaging the structure of the brain is obviously important and helpful, from the viewpoint of a psychologist it is much more valuable to be able to observe the brain in action and to relate this to the ongoing mental activity of the participant. Some of the earlier developments here resulted from implanting electrodes in the brains of animals, a method that is clearly of limited application to humans. Exceptions do occur, however; for example, when patients are undergoing brain surgery to treat intractable epilepsy. The brain itself does not contain pain receptors, and so the patient can remain conscious and report their experiences when different areas are stimulated. Of particular relevance to memory are studies involving the hippocampus. Early reports that this occasionally evoked specific and verifiable episodic memories have proved difficult to replicate; however, recent work suggests that such stimulation may evoke a feeling of déjà vu, a sense of familiarity when confronted with a quite novel complex stimulus event such as hearing someone playing a trumpet. Such an experience could have been interpreted by the patient as a genuine memory (Gloor, 1990; Vignal, Maillard, McGonigal, & Chauvel, 2007).

In addition to stimulation, implanted electrodes can be used to *record* from single cells, a procedure that is proving promising (Rutishauser, Schuman, & Mamelak, 2008). Although recording from implanted electrodes is giving exciting new data, its use is, of course, limited by the fact that it can only ethically be used in a very limited number of patients and is confined to brain areas that are directly relevant to treatment.

Transcranial magnetic stimulation (TMS)

A rather less invasive method of influencing the brain is offered by this method, in which a current is passed through a set of coils held close to the participant's head. This results in a magnetic field which can polarize or depolarize the underlying brain tissue, causing a temporary, hence reversible "lesion" that can then provide evidence for the importance of that area of the brain in the observed cognitive activities. **Transcranial magnetic stimulation (TMS)** can be delivered either as a single pulse at precise point in processing, for example before stimulus presentation, or used repeatedly, leading to a disruption of that brain area that can last for many minutes. It has the advantage that it allows the experimenter to control the situation, comparing performance with and without stimulation, in contrast to the brain observation studies we will discuss next. In such cases, unlike TMS, the investigator may observe that a particular area of the brain is activated during a specific task, but that does mean that it is *essential* for that task. TMS, like neuropsychological lesion studies, is able to go beyond this basic correlation between area and task and demonstrate that without this brain area, the task cannot be performed.

Limitations of TMS are that currently it tends to affect a relatively large area with its influence typically limited to areas near the surface of the brain. Furthermore, while in general safe, it can result in discomfort, and occasionally even seizure in susceptible patients. Nevertheless, as methods develop it is likely to continue to play an important role in cognitive neuroscience (see Widhalm & Rose, 2019 for a recent overview).

Transcranial direct current stimulation (tDCS)

Transcranial direct current stimulation (tDCS) is a procedure whereby a low direct current is delivered via electrodes on the skull to selected areas, resulting in a flow of current through the selected area of the brain which may increase or decrease the neuronal excitability of the area stimulated. Anodal stimulation with a positive voltage increases neuronal excitability, cathodal stimulation with a negative voltage reduces neuronal excitability, while sham stimulation which

KEY TERM

Transcranial magnetic stimulation (TMS): A technique in which magnetic pulses briefly disrupt the functioning of a given brain area; administration of several pulses in rapid succession is known as repetitive transcranial stimulation (rTMS).

Transcranial direct current stimulation (tDCS): A procedure whereby a low direct current is delivered via electrodes on the skull to selected areas, resulting in a flow of current through the selected area of the brain which may increase or decrease the neuronal excitability of the area stimulated.

A woman undergoing TMS of the brain.

emits a brief initial current that remains off for the remainder of the stimulation time may be used as a control condition. There is some evidence that it may reduce depression (Mutz et al., 2019), and a number of studies have claimed that it may be used for cognitive enhancement (Chill, Fitzgerald, & Hoy, 2016), although the evidence from this has been questioned (Horvath, Forte, & Carter, 2015). This approach has not currently had a major effect on our understanding of human memory.

Electro-encephalography (EEG)

This much more widely applicable method involves recording the ongoing electrical activity of the human brain. It is noninvasive and involves picking up the electrical activity of the person's brain through an array of electrodes on the scalp. This process records fluctuating voltages across the brain, ranging in frequency from a few cycles to 70 cycles per second or more. Electro-encephalography (EEG) is used clinically to detect epileptic foci that may result in seizures; it also plays an important role in studying sleep, with the various stages of sleep being identified with different frequency bands. EEG has been widely used to study cognitive function, for example showing a different pattern of activation when participants in a memory experiment are actively remembering or recollecting an experience as opposed to merely finding it familiar (see Chapter 8). However, EEG reflects a complex pattern of activation across the whole brain, and it may be hard to identify the contribution to this overall pattern that is associated with the performance of particular processes or a specific area. It does however have one major advantage over many methods of imaging the brain, that of temporal specificity, providing a more precise way of evaluating the brain's response to specific cognitive activities through event-related potentials (ERPs). These are obtained by time-linking an event to a specific component of the EEG. This involves precise timing, allowing each stage of performance of a task to be linked to the EEG activation at that specific moment. This can allow the effects of cognitive processing to be monitored

KEY TERM

Electro-encephalography (EEG): A system for recording the electrical potentials of the brain through a series of electrodes placed on the scalp.

Event-related potentials (ERPs): The pattern of electroencephalograph (EEG) activity obtained by averaging the brain responses to the same stimulus (or similar stimuli) presented repeatedly.

Electrophysiological recording of brain activity. The images on the screen show the distribution of brain activity across successive time periods.

over a period of milliseconds, hence providing a picture of the way in which the brain reacts to that specific event. Such ERP signals tend however to be weaker than the background EEG within which they are embedded, but nevertheless can be extracted by averaging over many repetitions of the same cognitive activity. While the location of evoked response signals is typically not precise, it is possible to identify broad regions of particular activity which may change over time, presumably reflecting the role of different brain areas in the successive processes involved in that particular task.

Magneto-encephalography (MEG)

While EEG and ERP signals reflect the variation in electrical voltage on the surface of the brain, such activity can also be detected by associated changes in *magnetic* activity using a technique known as **magneto-encephalography (MEG)**. This also uses a range of detectors around the head. It differs from ERP in being most sensitive to activity in the *sulci*, the valleys within the folds of the brain, whereas ERP is more sensitive to the peaks or *gyri*. MEG signals are less subject to distortion from passing through the skull and the electrodes than is the case with ERP. It gives a less complex pattern than ERP, and potentially offers a more precise localisation of its origin within the brain. Although substantially more expensive than ERP, these advantages are resulting in the increasingly wide use of MEG (see Figure 2.2).

KEY TERM

Magneto-encephalography (MEG): A system whereby the activity of neurons within the brain is detected through the tiny magnetic fields that their activity generates.

BLOOD FLOW BASED MEASURES

Both ERP and MEG measures have good temporal resolution; they allow the tracking of brain activity over periods ranging from milliseconds to seconds, but have poor spatial resolution; it is unclear where the activity originates within the brain. Much more precise localization is possible by using methods that rely on the assumption that when a particular area of the brain is active, this is reflected in its metabolism, usually measured in terms of the amount of oxygen being used by that area.

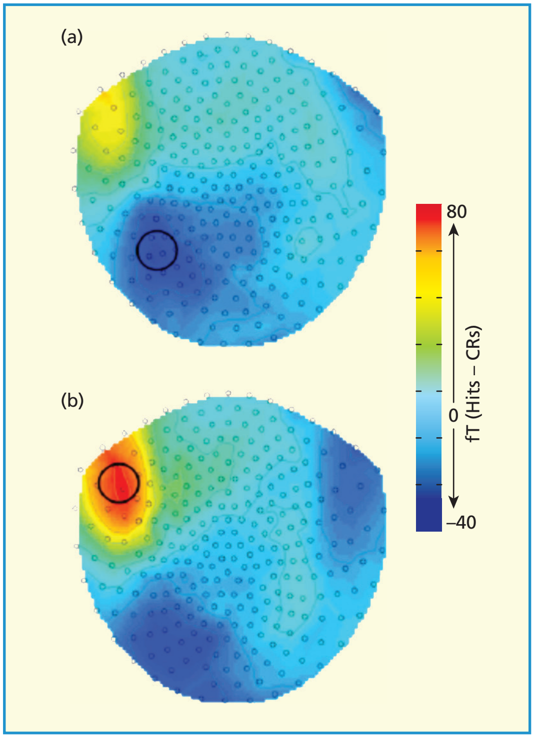


Figure 2.2 MEG reflects the rapidly changing activity of the brain across time. Level of activity is typically mapped by color, with brighter colors reflecting greater activity. The example shown is taken from a study by Horner et al. (2012). The brain activity linked to recognizing that a word had previously been presented is compared to that associated with the capacity to tell whether the given word had been presented together with that particular background. Activity peaked at two separate points. The early pattern shown in (a) peaks at 330 ms and is linked to recognizing words. The lower pattern (b), peaking about 60 ms, later reflects the capacity to link the word to its specific contextual scene. This second component was not found in patients with hippocampal damage. Reprinted from Horner et al. (2012), Copyright © 2012, with permission from Elsevier.

Positron emission tomography (PET)

The first of these methods to be developed was **positron emission tomography (PET)**. This involves injecting a radioactive tracer substance into the blood stream; it is conveyed to the brain, with areas of greater activity demanding greater blood flow leading to more radiation. An array of detectors around the head is then able to pick up such radiation, hence localizing areas of maximum activity. PET was very important during the early years of functional imaging. It has much poorer temporal resolution than ERP and MEG, but is much more spatially specific. A major drawback however is the need for radioactive reagents, potentially dangerous if the same participant is to be scanned repeatedly, and costly, as preparation requires a cyclotron, preferably on-site.

Because of this, PET has largely been replaced as a research tool by *functional magnetic resonance imaging* (fMRI), which also depends on measuring the flow of oxygen within different areas of the brain, and on the assumption that an active area of the brain will utilize more oxygen. The oxygen is carried by haemoglobin. As the oxygen is depleted, the haemoglobin changes its magnetic resonance signal. This can then be picked up by a series of detectors arrayed around the brain, with the pattern of receptor activation being used to locate the various areas in which oxygen is being depleted. This method has the advantage that it is non-invasive since it relies on activities that are already happening within the brain being *externally* detected. Activation can be relatively precisely localized, providing better spatial resolution than PET, especially with more recent equipment containing more powerful magnets. It does however provide relatively poor temporal resolution. The typical response to a stimulus will start 1 or 2 seconds after stimulus presentation, peak at 5–6 seconds, and return to baseline 10–20 seconds later; very much slower than EEG or MEG.

As we shall see, fMRI has already begun to play an important part in the study of human memory, though like all methods it

KEY TERM

Positron emission tomography (PET): A method whereby radioactively labeled substances are introduced into the bloodstream and subsequently monitored to measure physiological activation.

fMRI scans have become an important source of data in psychology. The patient is about to be slid into the machine that will create the magnetic field.

has its limitations. Although less expensive than PET, it is still sufficiently expensive and time-consuming in terms of analysis to make exact replication of studies relatively rare, with investigators tending to move on to the next question rather than checking the robustness of each study, resulting in problems of the reliability of observed results. The pattern of brain areas activated can be relatively large, resembling a mountain range of activation, although this is often simplified to show only the "peaks" (see Figure 2.3). Unfortunately, identifying such peaks will depend on a number of factors. First of all, on the comparison condition. A typical design will involve presenting a task, for example seeing and remembering a sequence of digits, together with a baseline control, for example seeing the digits but not attempting

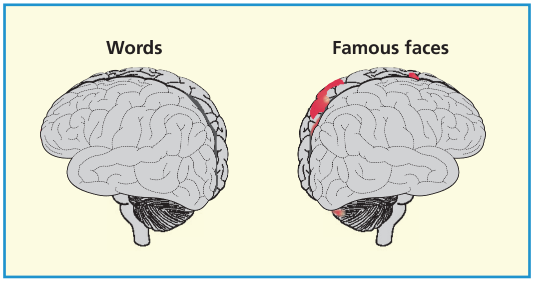


Figure 2.3 Brain regions associated with the remembering of words and famous faces by healthy controls. Reprinted from Simons et al. (2008), Copyright © 2008, with permission from Elsevier.

to remember them. The next step is to look at the difference between the patterns of activation across these two, typically using a *subtraction method* where what is shown is the *difference* in activation between trials when memory is required, and those when it is not. Finding an appropriate baseline condition to subtract is crucial and can be tricky, particularly with complex cognitive activities.

Having subtracted the baseline condition, we are left with a set of adjusted activation levels across the brain. Deciding which of these many differences is reliable and important presents a challenging statistical task whose outcome will depend on setting an appropriate significance level. Having achieved this statistically significant difference pattern, it must then be interpreted. In the case of a cognitive study, this will involve attempting to link the pattern to underlying psychological theory, not always an easy task, or one about which different investigators agree.

Multi-voxel pattern analysis (MVPA)

This and related problems has recently led to the development of a more automatic procedure known as *multi-voxel pattern analysis* (MVPA). A scan will result in a visual representation of the brain that can be divided into an array of tiny spatial areas known as voxels. In standard fMRI, each of these is treated as independent from the rest, hence losing information about any overall pattern resulting from the systematic co-occurrence of different areas of stimulation across the brain. MVPA uses powerful machine-learning techniques to look for cross-voxel regularities that occur in the brain, when the same event is presented repeatedly. Significance levels can be set in advance and the problem of possible experimenter bias reduced. Using this approach, the computer can be used as a pattern classifier, gradually building up a model of the brain's response to a particular type of stimulus, for example a human face or a house. Having acquired this statistical representation, the computer can then analyze new scans in which it can reliably detect whether houses or faces are presented (see Tong & Pratte, 2012 for a review).

Quite dramatic results have been obtained using the method which is sometimes referred to as "mind reading" since it appears to allow the scientist to know just what the participant is thinking. Commercial companies are already being set up claiming to use the method for lie detection (see Box 2.3). It is important to note, however, that it is not lying per se that is being detected, but the cognitive and emotional processes that are associated with lying. An attempt to use this method in an actual court case concluded that the method had not gained widespread acceptance among scientists, that its validity and accuracy had yet to be assessed in real-world settings and hence it should not be accepted as evidence (Shen & Jones, 2011).

THE CELLULAR BASIS OF MEMORY

This is a huge and highly active field, but one that has so far had relatively little impact on the analysis of memory at a cognitive level. Classic work by the Nobel Prize Laureate Eric Kandel used a very simple animal *Aplysia*, a sea slug, to analyze two basic types of learning, *habituation* and *sensitization*. Habituation was studied by repeatedly touching the animal's syphon; this resulted in withdrawal of its gill, a response that decreased systematically over repeated stimulation. The opposite effect, sensitization, occurred when touch was linked to the delivery of shock to the animal's tail, a basic form of classical conditioning as originally demonstrated by Pavlov with dogs. Repeated presentation of the touch-shock pairing can be shown to lead to gene expression, new protein synthesis, and the development of new synaptic connections, all of which are associated with the long-term retention of the enhanced response to touch.

Further research in this area has identified two potential mechanisms of learning, long-term potentiation (LTP) and *long-term depression* (LTD), and whose mechanisms have been extensively studied at the molecular level, implicating neurotransmitter systems and genes. While this level of biological analysis is likely in the future to have clear implications for the understanding of memory at the cognitive level, and vice versa, it does not yet feature strongly in the chapters that follow.

GENETIC APPROACHES

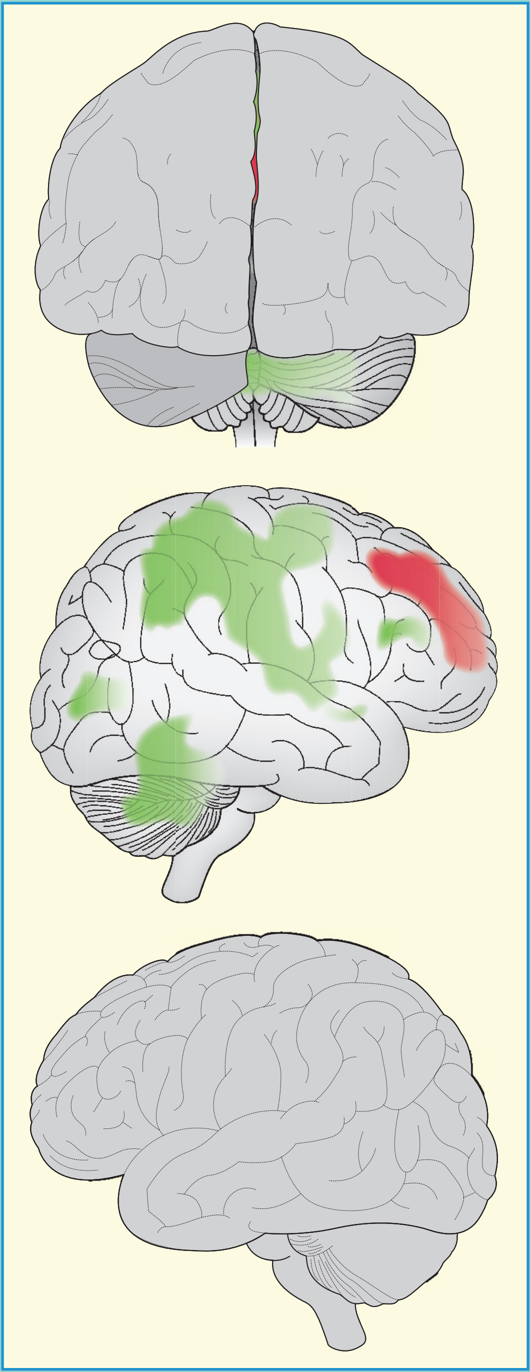
Sir Francis Galton, a cousin of Charles Darwin, was probably the first to focus attention on the field that has become known as behavioral genetics. He noted that talent in particular areas tended to run in families, the Bach family in music for example, while in the UK a small number of academic families who included the Darwins, Wedgwoods, and Hodgkins appear to have produced a surprisingly large number of talented scientists. Galton was aware of course that the members of such families had much more in common than genes, notably including an environment and social position that was likely to foster their talent and facilitate its further development within society. He noted however that "twins have a special claim upon our attention; it is, that their history affords means of distinguishing between the effects of tendencies received at birth, and those that were imposed by the special circumstances of their after lives" (Galton, 1869).

The basis of twin studies is the comparison between identical twins, who share 100% of their genes, and fraternal twins who on average share only 50%, the same as is likely for any nonidentical sibling. Of course twins are typically brought up together, which means that their environment is also likely to be common. An exception, however, is when twins are separated at birth and

KEY TERM

Long-term potentiation (LTP): A process whereby synaptic transmission becomes more effective following a cell's recent activation.

Box 2.3 Neuroimaging and lie detection



If "mind reading" is possible, could it not be used to tell whether a suspect is lying or not? A number of studies have explored this. In one study (Davatzikos et al., 2005), participants were given an envelope containing two cards, the five of clubs and the seven of spades, followed by a sequence of cards containing both other cards and examples of both. The task was to consistently tell the truth about possession of one of the cards and lie about the other. Brain activation was then recorded and a computer-based pattern analyzer used to identify those areas of the brain consistently accompanying truth and falsehood. The results are shown in Figure 2.4. Using the pattern analyzer, the experimenters were able to detect the instances of lying with over 80% accuracy.

It is important to bear in mind, however, that it is not lying per se that is being detected, but the activation of the certain areas of the brain which reflect a range of cognitive and emotional processes associated with lying. Such processes are likely to occur in other situations, particularly under stress, and in a legal situation may well be evoked in innocent people, emotionally disturbed by the threatening situation even when telling the truth. It is also not clear whether criminals, particularly those with psychopathy, will be equally emotionally aroused while lying. Furthermore, the guilty may be able to subvert the process by covertly engaging in other cognitive activities (Ganis, Rosenfeld, Meixner, Kievit, & Schendan, 2011).

Despite this, private companies are being set up claiming to detect lies using neuroimaging. In 2010, a hearing was held in Tennessee to decide whether fMRI lie detection could be

Figure 2.4 Different 3D views of regions showing relatively higher activity during truth telling (green) or lying (red). Reprinted from Davatzikos et al. (2005), Copyright © 2005, with permission from Elsevier.

(Continued)

(Continued)

accepted as valid scientific evidence. The CEO of one such private company presented evidence of scans which he claimed indicated the innocence of a defendant on a charge of fraud. A neuroscientist and a statistician were asked to comment on the technology, leading the judge to conclude that despite some support by peer-review publications the method was not widely accepted among scientists, had not yet been validated in real-world settings, and that a well-standardized protocol was not currently available, hence ruling out such evidence (Shen & Jones, 2011). A similar note of caution was reached in the UK by a recent committee of the Royal Society concerned with neuroscience and the law. They also noted that if reliable lie detection should become possible, there would be considerable ethical issues as to if and when such measures should be used (Mackintosh, 2011).

brought up within different families; the difference between the performance of fraternal and identical twins on any given function is then used to assess just how much is attributable to genetic and how much to environmental influences.

The whole area of genetic factors has been bedevilled by its association with the eugenics movement, originally driven by the fear in Victorian times that poorer and less intelligent people would have larger families, leading to a gradual degradation of the nation's intelligence. This has proved not to be the case; on the contrary, systematic measures of intelligence across a wide range of tests and countries shows a steady increase extending over many generations, called the Flynn effect after its discoverer (Flynn, 1987). A particular pernicious version of eugenics was developed by the Nazis in Germany who attempted to "purify" the population by encouraging the breeding of those who most resembled an invented racial type, the blond Aryans, coupled with the mass slaughter of those with "undesirable" genes such as Jews, gypsies, and the mentally handicapped. A milder echo of this issue arose in the US during the 20th century in connection with average differences in performance on standard intelligence tests between different races who do of course tend to grow up in radically different physical and social environments (see Neisser et al., 1996 for an extensive discussion).

Interest in genetics has grown substantially following the discovery some 50 years ago by Crick and Watson of the structure of the human genome, a structure that contains the genes that determine the way in which all organisms develop. This led to a huge effort focused on reading the genome, together with a growing interest in studies concerning the genetic basis of many aspects of life, including behavior. It had been known for many years that some diseases are genetically based. In some cases such as Huntington's Disease this was obvious because of the way in which it afflicted certain families, functioning as would be predicted by what was already known from earlier genetic studies. Other cases such as Down syndrome also proved to be *genetic* in the sense that they reflect chromosomal damage but *sporadic* in the sense that there is no evidence that it runs in families. Other diseases such as Alzheimer's are typically sporadic and probably not genetically determined, but can occasionally be found in a genetic form in which half the members of the family possess a gene leading them to succumb to the disease at an early age (see Chapter 16, p. 510).

However, although family and twin studies continue to provide valuable insights, much of the work on behavioral genetics comes from large population studies, typically measuring a range of psychological and behavioral measures and attempting to relate them to specific genes. This has tended to cause excitement in the press when a study appears to reveal "the gene for X," where X can be anything from intelligence to homosexuality. It is, however, proving increasingly