Human Neurobiol (1987) 6:67–80

Human Neurobiology

Introduction

Multiple memory systems and consciousness

E. Tulving

Department of Psychology, University of Toronto, Toronto, Ontario, Canada M5S 1A1

Summary. This Introduction to the Special Issue on Human Memory discusses some of the recent and current developments in the study of human memory from the neuropsychological perspective. A problem of considerable current interest, that of multiple memory systems, is a problem in classification. Much of the evidence for it is derived from clinical and experimental observations of dissociations between performances in memory tasks. The distinction between short-term and long-term memory is considered as an example of classification by dissociation. Current conceptualizations of multiple long-term memory systems are reviewed from the vantage point that distinguishes among three major kinds of memory – episodic, semantic, and procedural. These systems are briefly described and compared, and current views concerning the relation between them are discussed. The role of consciousness in memory is raised against the backdrop of the suggestion that it may be necessary to differentiate among several kinds of consciousness.

Key words: Multiple memory systems – Episodic memory – Semantic memory – Procedural memory – Memory and consciousness

"Memory" is the name given to the ability of living organisms to acquire, retain and use information or knowledge. The term is closely related to "learning", the two differing primarily in that learning is used in situations where the focus is on the first stage of memory, acquisition of information, whereas memory refers to the total process, or tends to be favoured in situations, where interest lies in the retention and use of the acquired information. More specifically, "learning" connotes gradual acquistion of new, relatively stable skills and behaviors, whereas "memory" implies retention, over short or long intervals, of acquired knowledge or previously experienced events, together with retrieval of such knowledge or conscious remembering of such events. Learning and memory can assume a large number of different forms and can occur in a wide variety of different situations. Different scientific disciplines study different aspects of learning and memory from different points of view.

Parallel tracks of memory research

Experimental study of human memory, as distinguished from its philosophical analysis, began a hundred years ago, when Hermann Ebbinghaus (1885) published his monograph, in which he described the quantitative results of his carefully controlled observations on learning and retention of verbal material. Shortly thereafter, following pioneering work by comparative psychologists such as George Romanes and Lloyd Morgan, Edward Lee Thorndike (1898) initiated the systematic experimental study of learning in lower animals. The approach to the study of memory and learning in both humans and lower animals in the two great traditions that began with Ebbinghaus and Thorndike was almost exclusively behavioral. There was little concern with brain function in this approach.

The idea that the brain plays a role in learning and memory was included among other speculations of Rene Descartes's and Franz Joseph Gall's. But it acquired scientific respectability only towards the end of the 19th century. One important inspiration for such a development was provided by careful clinical observations reported by the students of memory pathology such as Theodule Ribot (1882) and Sergei Korsakoff (1889). This work had little influence on research done under the banner of (mainstream) experimental psychology of learning and memory, being conveniently classified as "medical psychology." Since it was not experimental, it needed not be taken seriously. Another stimulant for the study of brain/behavior relations in learning was the work by the early pioneers of physiological psychology, a discipline known today under the name of behavioral neuroscience. Among the early students of behavioral neuroscience of learning, Ivan Pavlov (1927) and Karl Lashley

(1929) were the most creative and influential. The mainstream accepted the behavioral findings of their work, but left the "physiologizing" regarding learning, together with the whole problem of the relation between brain and behavior, to physiological psychologists. (Summaries of the historical developments in the study of learning and memory are available in the chapters of *The First Century of Experimental Psychology* (Hearst 1979) authored by Cofer (1979), Gottlieb (1979), Jenkins (1979), and Thompson and Robinson (1979).)

Thus, from the beginning, the scientific study of learning and memory has proceeded on several sets of largely parallel tracks, in several specialities, in relative isolation of one another. Today's research on memory, characterized by a great variety of orienting attitudes, methodological approaches, levels of analysis, and theoretical predilections, is being vigorously pursued in rapidly multiplying branches of the biological sciences. Relative insularity of the different specialties is still the order of the day, but there are some signs that the situation may be changing. The movement away from isolation is evidenced in and aided by interdisciplinary symposia, conferences, and publication ventures that have managed to build some bridges across different domains of the developing science of learning and memory (e.g. Lynch et al. 1984; Nilsson and Archer 1985; Olton et al. 1985, Rosenzweig and Bennett 1976; Squire and Butters 1984; Weinberger et al. 1985). The present Special Issue of *Human Neurobiology* is also meant as a modest contribution to the interdisciplinary communication and shared understanding about the tremendously complex problems of learning and memory.

The neuropsychological connection

The papers in this Special Issue approach the study of learning and memory from the neuropsychological point of view. Human neuropsychology is that branch of psychology that studies the relation between brain function and behavior (Kolb and Whishaw 1985). The neuropsychological study of human learning and memory entails a search for the understanding of memory through the understanding of the relation between brain function, on the one hand, and behavioral and experiental aspects of learning and memory, on the other. A good deal of relevant evidence is derived from clinical observations and laboratory experiments investigating impairment of learning and memory in patients suffering from brain damage. Papers in this issue of *Human Neurobiology* by Kinsbourne, Weiskrantz, and Schacter deal specifically with various aspects of the neuropsychological study of memory impairments. Other kinds of evidence are provided by observations of learning and memory in both normal and brain damaged individuals who have been administered psychoactive drugs. The paper by Lister and Weingartner reviews this branch of the neuropsychology of learning and memory. Still other evidence comes from the measurement of the metabolic and electrophysiological activity of the brain, and correlations of such measures with cognitive activities of the individual. The papers by Wood, and by Halgren and Smith, discuss the application of the techniques of cerebral regional blood-flow and event-related potentials to learning and memory.

It is a truism that the understanding of impairment of a function – by lesion, by drugs, or by some other means – necessarily requires the understanding of normal function. Conversely, empirical and theoretical light thrown on the impairment of a function necessarily illuminates the picture depicting normal function. (The same statements also apply to *facilitation* of function by lesions or drugs, but such facilitation is a much rarer phenomenon. Lesions sometimes facilitate certain kinds of learning in animals (e.g. Oakley 1980), and drugs such as alcohol have been shown to enhance "consolidation" in human memory (e.g. Parker and Weingartner 1984).)

The study of normal memory functions and the study of impaired functions would be expected to move hand-in-hand, mutually reinforcing each other, benefitting from each other's achievements, and providing the kind of feedback to each other that helps to chart the course of most optimal enquiry. In fact, for a long time in the independent existences of experimental psychology of memory and the clinical study of amnesia, there was little contact between the two fields. The absence of conventional standards of research in clinical studies of amnesia, on the one hand, and the clinical students' perception of experimental studies of memory as rigid and sterile, on the other, together with barriers of communication created by esoteric, and not always consistent, terminology in the two fields, were at least partly responsible for keeping them apart (Schacter and Tulving 1982). Inconsistent terminology is still hampering communication between practitioners and it undoubtedly frustrates outsiders interested in following the developments in the field, but it seems to be unavoidable in a pre-paradigmatic science such as that of learning and memory (Kuhn 1962).

Fortunately the situation has begun to improve, and at the present time it looks as if a fruitful symbiotic relationship is emerging between the study of memory by experimental psychologists, who today are called cognitive psychologists, and the study of amnesia by neuropsychologists. Several significant events can be identified, that have helped to bring about such a healthier development. One was the now famous case of H.M., whose strikingly "pure" anterograde amnesia was investigated and documented by Milner and her colleagues (e.g. Milner 1958, 1966, 1970) in a manner judged acceptable by experimental psychologists (e.g. Atkinson and Shiffrin 1968; Wickelgren 1973).

Another landmark development consisted in the reports by Warrington and Weiskrantz (1968a, 1968b, 1970, 1974) of a remarkable dissociation between two kinds of memory performance in densely amnesic patients and in normal control subjects. Warrington and Weiskrantz found that whereas their amnesic patients, as expected, did extremely poorly on tests of recognition and recall of recently studied verbal items, their performance was unimpaired on tasks that did not require conscious recollection of the original learning episode. In these latter tasks, patients would be given mutilated pictures of objects or words, or a few initial letters of words, and instructed to identify the object or word. Such identification performance was shown to benefit greatly from the recent encounter with the materials, thereby demonstrating the kind of learning that is now usually referred to as "priming," and the benefit, surprisingly, was approximately equal for amnesics and controls. The ability of amnesic patients to learn and to retain certain kinds of information had been described before. Thus, for example, Claparede (1911) said that his patient, after six years in the hospital, walked around in the halls without getting lost, although she claimed not to know where she was. Korsakoff (1889), too, mentioned various preserved memory functions in his patients. But these accounts, because of their anecdotal nature or perhaps because of the type of preserved learning in amnesia that they described, lacked the impact of Warrington and Weiskrantz's reports.

The third, less sharply demarcated but perhaps the most incisive, development was the adoption of more rigorous *experimental* methods of research by a new generation of students of amnesia. In addition to Milner, and to Warrington and Weiskrantz, other workers with good training in experimental psychology began exploring the capabilities of memory-impaired patients by using carefully controlled procedures, thereby effecting the transformation of the clinical study of memory disorders into a new, experimentally oriented field of neuropsychology of memory and amnesia (e.g. Butters et al. 1973; Cermak and Butters 1972; Cermak et al. 1973; Corkin 1968). Before this shift, the predominant orientation of research had been largely *psychometric*, consisting of administration to patients of various *tests*. A psychometric test provides a global measure of whatever "type" of memory function it is claimed to tap but it has no analytic power to dissect memory processes in a way that an experiment can. (For a note on the distinction between memory *tests* and memory *experiments*, see Tulving 1983, pp 219–220).

A final factor shaping the development of the new field of neuropsychology of memory and amnesia has been the relative success of the search for an appropriate animal model of human amnesia. At the beginning this search was frustrating and unproductive, for reasons that only gradually became clear, and even now writers have reservations concerning the possibility of its complete success (Morris 1985). But excellent progress has been made (e.g. Hirsh 1974; Gaffan 1985; Mishkin and Petri 1984; Mishkin et al. 1984; Pribram 1984; Zola-Morgan and Squire 1985). The progress has been achieved not only because of refinement of approaches and techniques, but also because it has now been realized that it is necessary to differentiate between different kinds of learning and memory within species before making cross-species comparisons within corresponding tasks (Weiskrantz 1977). Thus, although the work with animals has some obvious limitations – for instance the absence of techniques for analytical and experimental separation of *experience* from *behavior* in nonverbal organisms, a separation that is crucial to defining higher forms of memory – the advantages of using animals in the study of learning and memory are beyond dispute (Olton 1985a, 1985b).

As a result of all these developments and achievements of the neuropsychology of learning and memory, there is optimism in the air today, and hope that the days of slow progress are behind us and that the future will include some genuine breakthroughs.

From dissociation to classification

One of the currently "hot" issues in the science of learning and memory has to do with the *classification* of forms of memory. Is memory basically a unitary complex, or is it comprised of two or more varieties, or systems? Almost everyone finds it convenient or useful to distinguish between different *forms* or *kinds* of learning and memory for heuristic purposes, for describing specific problems, methods, and findings, and differences among them. But the question of whether or not there is anything in nature that corresponds to these or comparable categories is being vigorously debated.

Many mainstream cognitive psychologists still favor the orienting attitude that memory is a unitary entity of some sort. They assume that the apparent differences in manifestations of memory represent nothing more than different combinations and concatenations of particular cognitive processes, all operating within the bounds of "one large memory." The extreme form of this orienting attitude is that the whole mind is unitary, and that "all the higher cognitive processes, such as memory, language, problem solving, imagery, deduction, and induction, are different manifestations of the same underlying system" (Anderson 1983, p 1). Many neurobiological students of learning and memory similarly assume, at least implicitly, that "learning is learning" and "memory is memory." More often than not they fail to limit their conclusions about "learning" or "memory" to the specific forms thereof that they have observed, nor do they exhibit much curiosity about forms of learning or memory other than the specific one or ones they use in their own research.

Between the two extremes of cognitive psychologists and molecular neurobiologists are other researchers, particularly those with a neuropsychological orientation, who have accepted the basic tenet that "memory" is only the generic name of several (or many) separable but interrelated brain/behavior/cognition systems. All systems possess the capability of bringing about changes in behavior or experience, but different systems are responsible for such changes in different domains of the individual's interaction with the world and they operate according to somewhat different principles.

Evidence for multiple memory systems is provided by experimental, neuropsychological, psychopharmacological, and developmental *dissociations* between memory performances in a variety of stituations. These dissociations can be found in overt behavior and in verbal reports of the "contents" of consciousness (e.g. Eich 1984; Jacoby and Witherspoon 1982; Schacter and Moscovitch 1984; Tranel and Damasio 1985). They can also be found in the metabolic and electrophysiological activity of the brain, revealed by techniques such as the measurement of regional cerebral blood flow (Wood, this issue) and event-related potentials (Halgren and Smith, this issue). Although strong dissociations have been observed, many others are only moderate, leaving room for a variety of different interpretations.

The problem of multiple memory systems is a problem in the *classification* of learning and memory (Tulving 1985c, 1986). The results of a dissociation experiment, whether natural or arranged in the laboratory, can provide invaluable information for the purpose of classifying learning and memory, even if they do not always greatly illuminate the nature of neurobiological *mechanisms* or psychological *processes* underlying learning and memory. The logic of dissociation experiments is discussed in this issue by Lister and Weingartner, and by Kinsbourne. A critical requirement of successful research on classification by dissociation is the use of *multiple tasks*. The dissociation logic with multiple tasks is straightforward: If an experimental treatment, a focal brain lesion, a drug, or a stage of ontogenetic development has an effect on, or is correlated with, performance in memory tasks A, B, and C, but has no similar effect or correlation in performance in memory tasks X, Y, and Z, then it can be concluded that tasks A, B, and C have something in common that X, Y, and Z do not. Further research can then be undertaken to explore the identity and to evaluate the significance of that something (cf. Neely and Durgunoglu 1985; Roediger 1984; Shoben and Ross 1986). The success of this kind of detective work depends, among other things, on evidence or hypotheses concerning the constituent components of the learning and memory tasks used. This evidence, in turn, depends on experimental and theoretical analysis of the effects of variables and treatments on different learning and memory tasks.

A case study in dissociation: short-term and long-term memory

Dissociations constitute necessary but not sufficient conditions for classifying tasks in different categories and for drawing inferences about memory systems and subsystems (Kinsbourne, this issue). Stronger evidence in support of multiple memory systems is provided by the *convergence* of comparable evidence from different sources (experimental, neuropsychological, developmental, and neurochemical) and expressed in different ways – in behavior, introspective reports, and measurement of brain activity. Thus, the case for multiple memory systems is strengthened by the finding of similar dissociations across different domains of investigation.

Consider the distinction between short-term and long-term memory that can be traced back to William James (1890) and that was introduced into experimental psychology by Broadbent (1958). The distinction is accepted at some level by most cognitive psychologists (e.g. Bjork 1975; Craik and Levy 1976; Shiffrin 1975), the prevalent view is that it is one of differences between processes (Craik and Jacoby 1975). The earlier idea that short-term and long-term memory constitute different memory *stores* (Atkinson and Shiffrin 1968; Waugh and Norman 1965) is less popular (but see Broadbent 1984). The "stores" models were questioned because they entailed the assumption that the processes of short-term and long-term memory were very much the same, and that the two stores differed primarily with respect to their own *properties*, such as capacity, durability of traces, and susceptibility to interference, an assumption that did not pass critical scrutiny (Craik and Lockhart 1975).

Hypothetical "stores" of cognitive psychology, however, are not identical with memory "systems" that are defined in terms of brain/behavior/cognition relations and that differ from one another with respect to variables such as the kind of information that they handle optimally, and operating procedures and principles (Tulving 1984a, 1985b). Indeed, several lines of converging evidence exist for the neuropsychological reality of short-term and long-term memory systems.

First, experiments on free recall of word lists with normal subjects have shown that independent variables such as the length of the list, the rate of presentation of words, and the number of language-categories in the list (one, two, or three languages) affect the recall of words from the early and middle portions of the list but not from the end of the list (e.g. Tulving and Colotla 1970). Second, similar free-recall experiments comparing normal and amnesic subjects have shown that amnesics' recall performance is impaired in relation to that of normal subjects, but that the impairment entails words from the early and middle portions of the list, and not those from the end of the list (e.g. Baddeley and Warrington 1970). Third, double dissociations between short-term and long-term memory performances have been observed in brain-damaged patients (Shallice 1979; Weiskrantz, this issue). Fourth, experiments have shown that alcohol-intoxicated subjects are impaired in recall of words from the early and middle portions of the list and not impaired in the recall of words from the end of the list (e.g. Jones 1973).

These related findings with normal, amnesic, and alcohol-intoxicated subjects converge on the conclusion that one system (short-term, or *primary* memory) mediates recall of information immediately after its presentation, and that another system (long-term, or *secondary* memory) mediates recall of information after even only a few seconds' worth of interpolated activity. The functioning of secondary memory, but not that of primary memory, is impaired by lesions that produce amnesia, as well as by alcohol, list length, and a number of other such variables (Glanzer 1972).

Although these data, as always, are open to alternative interpretations, they do make it meaningful to pose questions about the neuroanatomical correlates of short-term and long-term memory (Weiskrantz, this issue), questions whose answers further converge on the concept of a "short-term memory system." Other related experiments then guide further elaboration of the concept of short-term memory and the properties of the short-term memory system.

A further illustration of the convergence of different lines of evidence on the distinction between primary and secondary memory is seen in an experiment of Wright et al. (1985). They tested recognition memory in pigeons, monkeys, and university students. On each trial, subjects saw a set of four successively presented, previously not seen, complex visual stimuli. A single "old" or "new" recognition probe item was given immediately after inspection of the list, or at variable intervals measured in seconds. A graphic summary of the results is shown in Figure 1. The data for all three groups yielded a pure recency effect (recognition lowest for the first item seen in the list, highest for the last item) when the test was given immediately after the inspection of the list, and a pure primacy effect (recognition highest for the first item, lowest for the last item seen in the list) when the test was given some time later. The data also showed that the recognition of the first list-item *increased* over the retention interval in all three groups. The groups differed only with respect to the length of the retention interval required for the transformation from the recency effect to the primacy effect: 10 s for pigeons, 30 s for monkeys, and 100 s for students. These data are reminiscent of the positive and negative recency effects in free (Craik 1970) and paired-associate (Madigan and McCabe 1971) recall of words, effects that can also be related to the distinction between primary and secondary memory.

If we assume that the 0-second performance in the Wright et al. (1985) experiment is heavily weighted with the output of the short-term memory system, whereas the delayed performance reflects primarily the output from the long-term system, we can conclude that (a) the distinction between short-term and long-term memory holds for lower animals as it does for humans, (b) the short-term memory system can operate independently of language, and (c) the durability of short-term memory information varies with the species. Somewhat more speculatively, with regard to the transformation of the recency effect into the primacy effect, and the *increase* in recognition of the first list item over the retention interval, it is possible to argue that information in short-term memory *inhibits* the use of related information in long-term memory. When the findings such as those reported by Wright et al. (1985) are theoretically integrated with the results of numerous other experiments aimed at the identification of the properties of short-term and long-term memory, and the clarification of the nature of the relation between them, they provide good support to the hypothesis that short-term (primary) and long-term (secondary) memory exist as separable but normally closely interacting systems. The search for further subdivisions of the two systems then is encouraged by findings of dissociations within short-term memory (e.g. Baddeley and Hitch 1974; Bjork and Healy 1974; Hitch 1985) as well as within long-term memory.

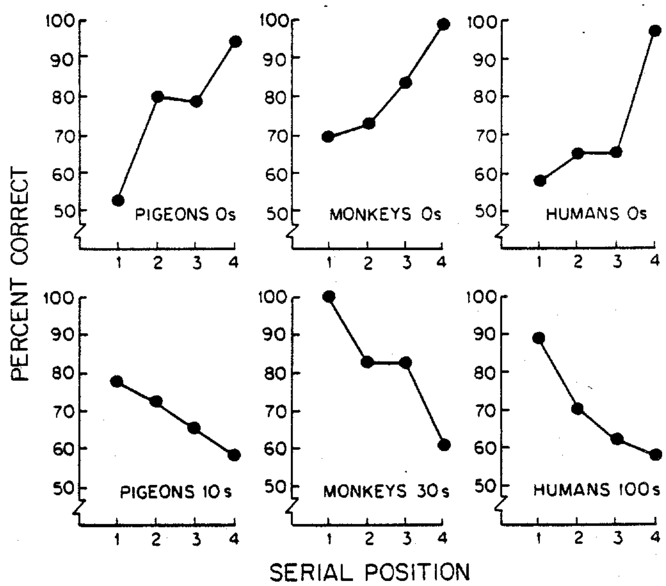

Fig. 1. Primacy effects in *immediate* tests, and recency effects in *delayed* tests of recognition of complex visual stimuli in pigeons, monkeys, and people. Subjects inspected four successively presented stimuli on each trial, they were then tested for Yes/No recognition of a probe that either matched one of the presented stimuli or represented a new, "different" stimulus. The test probe was displayed either immediately after the presentation of the last inspection stimulus or after an unfilled interval measured in seconds. Probability of correct recognition of presented stimuli is shown as a function of their serial position in the order of presentation. Data are shown for the immediate tests (0 s) and for the tests at the longest retention interval used with each species (10 s, 30 s, and 100 s, for pigeons, monkeys, and people, respectively); other data are available in the original publication (after Wright et al. 1985)

Multiple long-term memory systems

Long-term memory can readily be classified into separable but normally interrelated and interacting systems.

Table 1. Classificatory schemes of human memory

Level	Tulving	Weiskrantz	Cohen and Squire	Kinsbourne	Schacter
III	Episodic memory	Event memory		Episodic memory	Explicit memory
			Declarative memory		
II	Semantic memory	Knowledge systems			
				Semantic memory	Implicit memory
I	Procedural memory	Associative memory Priming	Procedural memory		

Although some theorists find such classification superfluous and unparsimonious, many others deem it a necessary precondition of any substantial progress in the understanding of learning and memory. The attempts to penetrate beyond the apparent continuity of learning and memory phenomena to their dissociable subservient brain structures and mechanisms have led to a number of tentative classificatory schemes of long-term memory. We consider these schemes next.

A sample of current ideas regarding multiple memory systems is shown schematically in Table 1. The sample summarizes the ideas held by some of the contributors to the present Special Issue, plus the vigorously advocated position of Cohen and Squire (Cohen 1985; Cohen and Squire 1980; Squire 1986). It does not include comparable ideas based on work with lower animals (e.g., Oakley 1981, 1983). Differences exist between the schemes in Table 1, not only in terminology but also in the substance of the belief regarding memory systems. Nevertheless, there is reasonably good agreement at a general level among the proponents of various schemes.

The systems are listed in Table 1 in an order that reflects their general capacity of representation and computation, as well as their assumed sequence of evolution and development. More powerful and sophisticated systems, and those appearing later in evolution and development are at the top, less powerful and phylogenetically and ontogenetically earlier ones are at the bottom. Systems listed under one writer's scheme correspond, at least roughly, to those shown at comparable levels in others' schemes.

Episodic memory

The "highest" memory system is episodic memory. It is the system that enables people to remember personal happenings from the past. Episodic remembering is, in its essence, a *mental* phenomenon in that it entails a conscious experience of an unique kind, one that every normal human being recognizes as such. It is different from other kinds of mental experiences, such as perceiving, imagining, dreaming, and hallucinating, in a way that is unmistakable phenomenally but difficult to describe verbally. William James, who has remained unsurpassed in his ability to translate mental happenings into words, distinguished between *remembering* one's own past states and experiences, and *knowing* (James's term here is "conceiving") someone else's: "Remembrance is like direct feeling; its object is suffused with a warmth and intimacy to which no object of mere conception ever attains" (James 1890, p 239).

Modern writers have stayed close to William James in their conceptualizations of episodic memory. Weiskrantz's definition of episodic memory (Weiskrantz refers to it as event memory), for example, follows James closely: "Memory for events is concerned with specific personal past experiences" (this issue). Every content word in this brief definition counts. "Specific" is to be distinguished from "generic" (Hintzman 1978) or "categorical" (Estes 1976) "knowledge of the world" (Lockhart et al. 1976), and from "generic" knowledge directly acquired through specific episodes (Watkins and Kerkar 1985). "Personal" emphasizes the central role played by the self in the re-experienced past: in episodic remembering the rememberer is always an observer or a participant in the mentally recreated earlier real-life happenings. In the retrieval of semantic memory, and in the execution of skills acquired through procedural memory, he is not. "Past" reminds us that other forms of memory need not refer to, represent, or recapitulate the past, despite the fact that the individual's knowledge of the world and other forms of learned behavior have been shaped by past experiences and past behavior. "Experiences" in Weiskrantz's definition is to be juxtaposed with "behaviors" or "responses" of other memory systems, such as procedural (Cohen and Squire 1980), semantic (Kinsbourne, this issue), and priming and associative learning (Weiskrantz, this issue). "Experiences" emphasizes the primacy of the inner, phenomenal nature of episodic remembering; if refers to introspective, conscious awareness of the veridicality and pastness (Tulving 1983) of the mentally constructed analogues of experienced events. It is this conscious awareness that makes episodic remembering "explicit" and distinguishes it from the forms of "implicit" memory in which the same kind of consciousness is lacking (Schacter, in this issue).

Like other major systems, episodic memory may consist of a number of subsystems. One possible division is between subsystems that mediate recall and recognition. Experimental dissociations between recall and recognition have been known for some time (Anderson and Bower 1972; Kintsch 1970) but as long as converging evidence from other domains of memory research was lacking, no conclusions about basic differences between recall and recognition were warranted (cf. Tulving and Bower 1974). Now, however, reports of pathological dissociations between recall and recognition have been published, showing that brain damage may affect these two episodic-memory performances differentially (Butters et al. 1985; Hirst et al. 1986; see also Huppert and Piercy 1976). Such *converging* evidence enhances the attractiveness of the idea that recall and recognition are subserved by different brain mechanisms, although alternative explanations cannot yet be rejected. One such is that performance in recognition, but not in recall, may be based on the memory system that mediates priming (Jacoby 1982; Mandler 1980) and that is known to be spared in amnesia (Schacter, this issue); another is the venerable standby explanation that the apparent dissociation may be an artefactual consequence of differences in the "difficulty" of the two tasks (cf. Lister and Weingartner, this issue).

Semantic memory

At the next level of the classificatory schemes we find semantic memory. The term was introduced into the literature by Quillian (1966), and the distinction between episodic and semantic memory, as "two parallel and partially overlapping information processing systems" was proposed by Tulving (1972, p 401). Semantic memory in Tulving (1972) was defined in close reference to knowledge expressible in language, but it is now conceptualized much more broadly, being appropriately defined as "knowledge of the world" (Lockhart et al. 1976).

Terminological variations on "semantic" memory, commented on by Kinsbourne in his paper in this issue, are found in abundance. Other writers have referred to semantic memory as "generic" (Hintzman 1978) or "categorical" (Estes 1976) memory. In the present Special Issue, Weiskrantz's "knowledge systems," and Lister and Weingartner's similar term "knowledge memory" correspond to semantic memory. Kinsbourne uses "semantic memory" in a broader sense than others do, subsuming under that rubric also the third main category shown in Table 1, namely procedural memory. Halgren and Smith's references to "cognitive memory" in their paper in this issue are to the combined category of episodic and semantic memory; it excludes procedural memory. Squire (1986) groups episodic and semantic memory together under "declarative" memory. He distinguishes between them heuristically, but denies them any status as separable brain systems.

I have described the properties of semantic memory, and discussed both the similarities and differences between semantic memory and the other two major systems, at greater length elsewhere (Tulving 1983, see also 1984b, 1985a, 1985b). It is a large system that is ripe for further subdivisions (e.g. Miller and Johnson-Laird, 1976, pp 150 – 152; Warrington 1984). Semantic memory allows the individual to construct mental models of the world, both concrete and abstract. It makes possible the cognitive representation of objects, situations, facts, and events, and the utilization of information thus represented in the absence of the original stimulus events and complexes. Unlike episodic-memory information, semantic-memory information about a particular object, situation, or event can be shared by different individuals, and much of it is indeed widely shared. If a friend telephones you in the middle of the night and tells you that "Aardvarks eat ants," your episodic memory allows you to remember the (strange) episode as such, whereas your semantic memory mediates your knowledge, newly acquired or already in existence, about the dietary preferences of the mammals with long snouts whose name appears early in the dictionary. In "source amnesia," discussed by Schacter in this issue, the patient would not remember the telephone call, but he could make an intelligent guess about the feeding habits of aardvarks. The dissociation suggests that episodic information is rapidly lost while the semantic knowledge is retained.

Procedural memory

Procedural memory enables organisms to retain learned connections between stimuli and responses, including complex stimulus-response patterns and sequences, that need not refer to any state external to the organism. Acquisition of procedural-memory information occurs slowly; the acquired information in procedural memory, unlike that in higher systems, has no truth value; expression of information in procedural memory is possible only through behavior, not symbolically; and this expression can occur "automatically," in the absence of directed attention (Tulving 1983, 1985a). This conceptualization of procedural memory, similar to that proposed by Cohen and Squire (1980), is very broad, and further natural subdivisions are highly likely to emerge from future research. Weiskrantz's (this issue) categories of "priming" and "stable associative memory" represent a step in this direction.

Schacter (this issue, see also Graf and Schacter 1985) refers to his distinction between "explicit" and "implicit" expressions of memory as *descriptive* only. It is therefore orthogonal to the systems of other writers, all of which are meant to be ontologically real. His dichotomy is included in Table 1 for the purposes of comparison. Since the hallmark of explicit memory is the rememberer's conscious awareness of past events, and the origin of knowledge in such events, whereas implicit memory operates without such awareness, explicit memory is akin to episodic memory, and implicit memory to the combined category of semantic and procedural memory. In this respect, Schacter's descriptive dichotomy is most similar to Kinsbourne's (this issue) two brain systems.

The distinction between procedural and propositional (declarative) memory is now widely accepted not only in its psychological aspects but also with respect to the underlying neurophysiological mechanisms, and researchers are busy working out the properties of the two systems. The distinction between episodic and semantic systems, on the other hand, is being hotly debated (e.g. Anderson and Ross 1980; Crowder 1986; Herrmann and McLaughlin 1973; Hintzman 1984; Kinsbourne 1986; Kihlstrom 1984; Lachman and Naus 1984; Lewis 1986; McKoon et al. 1986; Ratcliff and McKoon 1986; Roediger 1984; Shoben et al. 1978; Spear 1986; Tulving 1983, 1984b, 1986). The problems involved are complex, although much of the debate revolves around issues such as the principle of parsimony, interpretation of relevant evidence, and the usefulness of neuropsychological findings.

Relations between systems

One of the many open problems concerning multiple memory systems has to do with the relation between various systems. Two different specific proposals have been made. One holds that procedural and declarative memory constitute two *parallel* systems of memory, with a further subdivision of declarative memory into the *parallel* subdivisions of episodic and semantic memory (Squire and Zola-Morgan 1985, p 140; see also Squire 1986). Another view is that episodic memory is embedded in and supported by semantic memory, and that semantic memory is embedded in and supported by procedural memory (Tulving 1985a). The two alternative arrangements, which can be referred to as "parallel" and "embedding" hypotheses, respectively, are schematically depicted in Table 2. Although I also favoured the parallel hypothesis at one time (Tulving 1983), I adopted the embedding hypothesis (Tulving 1984b, 1985a) when it appeared that the parallel hypothesis could not be easily reconciled with other ideas concerning the relation between procedural and declarative memory.

One such idea concerns the nature of dissociations in performance of various learning and memory tasks attributable to brain lesions. The parallel hypothesis, for instance, leaves open the possibility of *double* dissociations between procedural and declarative memory, including the possibility that lesions may occur that lead to the loss or impairment of tasks heavily dependent on procedural memory without similarly affecting tasks highly dependent on declarative (semantic and episodic) memory. A large literature exists describing single dissociations of various kinds (see Kinsbourne's, Schacter's, and Weiskrantz's articles in this volume, also Hirst 1982; Moscovitch 1982; Parkin 1982; Rozin 1976), whereas double dissociations involving procedural and declarative memory have not been observed, as noted by both Kinsbourne and Weiskrantz in their papers in this issue (but see Martone et al. 1984 for a possible exception).

Table 2. Relations among human memory systems

Cohen and Squire	Tulving
Memory ↙ ↘	Procedural
	↑
Procedural Declarative ↙ ↘	Semantic
	↑
Episodic Semantic	Episodic

Note: *Arrows* are to be interpreted as "subdivided into" in Cohen and Squire's scheme, and as "embedded in" or "depends on" in Tulving's scheme

Another idea that fits better into the embedding hypothesis than the parallel hypothesis has to do with the evolution and development of the two systems. If we accept the notion that procedural and declarative memories are two parallel systems of memory (Squire and Zola-Morgan 1985), then we might expect to find species, or developing individuals within a species, in which the two systems develop together, as well as those in which the development of either one of the systems precedes that of the other. Such a hypothetical state of affairs is at variance with the plausible and widely accepted assumption that the development of the procedural system precedes that of the declarative system, both phylogenetically and ontogenetically (Squire 1982) and with the fact that no findings contrary to the assumption have been reported. For these reasons the embedding hypothesis is preferable to the parallel hypothesis.

Amnesia and memory systems

Theoretical ideas concerning classification of learning and memory are related to but not identical with theoretical ideas concerning the nature of amnesia. Amnesic patients may provide evidence regarding dissociations, and hypothetical classificatory schemes may be useful in making sense of observed dissociations, but the link is flexible. Contributors to the Special Issue discuss the matter.

Weiskrantz points out, that the problem is still under intense debate as to the relation between the putative memory systems on the one hand and the pattern of impaired and preserved learning and memory functions on the other hand. Of the contributors to this issue, Kinsbourne is most explicit in arguing that anterograde amnesia reflects an impairment of episodic memory, in keeping with the position adopted earlier (Kinsbourne and Wood 1975, 1982; Wood et al. 1982) and in agreement with other theorists, who have expressed similar views (Parkin 1982; Rozin 1976; Schacter and Tulving 1982). Weiskrantz also leans towards essentially the same hypothesis when he says that all memory systems other than event memory can be found intact in amnesia, thus implicating the critical involvement of the event-memory system (cf Warrington and Weiskrantz 1982). A diametrically opposite view is held by Squire and Zola-Morgan (1985), who assert that both episodic and semantic memory are impaired in amnesia. We are witnessing here the classic case of disagreement on selection and interpretation of data, compounded perhaps with difficulties of terminology.

Schacter agrees with Kinsbourne and Weiskrantz that the most striking feature of amnesia is the amnesics' inability to recollect explicitly personal experiences, including episodes of learning of new skills. But he does not see any strong evidence in support of the hypothesis that amnesia represents a highly selective impairment of the episodic system, since the amnesics' acquisition of new factual and associative knowledge, in the absence of any conscious recollection of the learning episode or episodes, is also impaired. Schacter's conclusion is based on his use of the strict criterion in the application of the logic of dissociation: He would be willing to accept the dissociation between remembering of episodes (explicit memory) and learning of new semantic knowledge (implicit memory) as support for the corresponding systems only if the semantic learning was completely *normal* in amnesic patients. Although amnesic patients can acquire new factual and associative information while remaining unaware of the learning episode, the semantic learning they exhibit is not "normal." Hence Schacter's conclusion that the evidence he discusses does not support the hypothesis that amnesia is an impairment of the episodic system.

Consciousness and amnesia

One of the recent developments in the study of human memory and amnesia entails the emergence of researchers' sensitivity to the problem of the relation between memory and consciousness. Like all problems that scientists feel they can solve or at least make some progress towards solving through the use of objective methods, this one too has many ramifications. But its essence can be put simply: what role, if any, does consciousness play in the operation of the memory system or systems?

The problem of consciousness and memory is different from problems of consciousness with which many generations of thinkers have wrestled without notable success, problems such as what consciousness *is*, and how it emerges from the physical-chemical brain activity. These questions may well turn out to be unanswerable within the constraints of scientific methods. Rather, the problem concerns the selective but systematic occurrence of conscious awareness in remembering, as well as in other mental activities: Why are we – why must we be – consciously aware when we remember a recent event that we have witnessed, and why is the *same kind* of awareness missing when we use our stored knowledge, say, in solving a new complicated problem? Some light is thrown on this problem by the analysis of consciousness in amnesia.

Amnesia has been characterized for a long time as a serious defect of memory. In such a characterization the facts concerning impaired *behavior* have always been prominent: amnesic patients cannot recall or recognize recently experienced events, they cannot acquire new facts about the world, they cannot answer questions pertaining to their lives before the onset of amnesia, and so on. The recent concern with the contrast between preserved and impaired learning and memory functions in amnesia have resulted in the realization that amnesia is essentially an impairment of *consciousness* rather than that of behavior. As discussed by several contributors to the Special Issue (Kinsbourne, Schacter, Weiskrantz), amnesic patients can learn many new skills and acquire new knowledge. Their main problem is that they do not *remember* such learning, and hence are *not aware* of the fact that they now possess the newly acquired skills. Schacter, for instance, in his paper (this issue) describes the work done at the Unit for Memory Disorders at Toronto in which amnesic patients laboriously but successfully learned to write simple computer programs (Glisky et al. 1986). Although they retained this new knowledge over time as well as normal subjects did, they did not remember having learned it and they did not know they knew how to write any programs. The same observation has been made over and over again by many students of amnesia.

Thus there is in amnesia a sharp dissociation between knowledge as expressed through behavior and knowledge entailed in introspective awareness. Within this general picture there are gradations; some kinds of new knowledge are acquired by amnesics more readily than others. But the dissociation between behavior and consciousness is strong. Amnesics can learn new skills and knowledges, even if very slowly and with great effort; they can consciously remember neither such learning nor its fruits, regardless of the amount of time spent in and effort expended on the activity.

Amnesia as a pathological condition of consciousness has not been discussed at length by contemporary students of memory, although the situation is changing. Kinsbourne (this issue) characterizes amnesia as an impairment of episodic memory, observing that the limits of amnesia are the limits of awareness. Warrington and Weiskrantz (1982) focus on the dissociation between amnesics' knowledge and their inability to provide commentary on that knowledge. Schacter (this volume, also Schacter 1985) describes amnesia as a defect of "explicit" memory, and not of "implicit" memory. All these notions implicate consciousness in the defective "memory."

Varieties of consciousness

If we do think of amnesia as a disorder of consciousness, it becomes necessary to distinguish between different kinds of consciousness, because a simple claim that amnesia is an impairment of "consciousness" is demonstrably wrong. In many respects, the consciousness of an amnesic patient is indistinguishable from that of a normal person, in other respects it many be quite different. Classical amnesics are perfectly aware not only of their surroundings and their presence in it, as well as the fabric of happenings in it, but they are also, or can become, aware of the states of the world elsewhere. Such intact awareness is a part of the clinical definition of amnesia. The conscious awareness that is missing in severe amnesia has to do with familiarity and personal reference in recreations of the past, and with the subjective *time* in which the amnesic himself is an actor, planner, or even just an observer of happenings. In anterograde amnesia, the patient is unaware of the events in time since the onset of the condition; in retrograde amnesia, the patient's consciousness has a void for personal happenings and their consequences before the onset of the condition. In extreme cases we may find that an amnesic patient's feelings of "warmth and intimacy" about himself have been replaced by mere conceptions, comparable to those he as about some other (close) person. The amnesic patient is conscious, but his consciousness is different from that of a healthy person.

To distinguish between the kind of consciousness that entails the knowledge of the world (semantic memory) and that is largely preserved in amnesia, and the kind that entails remembrance of the subjective past as well as apprehension of the future and that is impaired in amnesia, I have suggested the terms "noetic" (knowing) and "autonoetic" (self-knowing) consciousness (Tulving 1985b). Noetic consciousness accompanies the processes of semantic memory. Autonoetic consciousness is a necessary correlate of episodic memory. It not only provides the familiar phenomenal flavor of recollective experience, it also defines the individual's personal identity and inner existence through subjectively experienced time – past, present, and future (Ingvar 1985).

Thus, amnesia can be described as a selective impairment of episodic memory (Kinsbourne, this issue, also Parkin 1982, Rozin 1976), event memory (Warrington 1979; Weiskrantz, this issue), or explicit memory (Schacter, this issue). Semantic memory, procedural memory, and implicit memory are seen as relatively preserved. Amnesia can also be characterized as a selective impairment of autonoetic consciousness, with relative preservation of noetic consciousness (Tulving 1985b). In this formulation, different kinds of consciousness, and different kinds of conscious awareness, are assumed to represent inherent functional properties of those brain structures or mechanisms that subserve different kinds of memory. The evidence in support of these ideas, derived mostly from clinical observation and experimental analysis of behavioral and experiential consequences of brain lesions is still highly fragmentary. The hypothesis that amnesia is an impairment of episodic memory and autonoetic consciousness, like any other current hypothesis concerning the nature of amnesia, serves the primary function of guiding future research into memory and amnesia. The matter will be settled in the future.

The 'Special Issue'

The authors of the six papers in the 'Special Issue' share the neuropsychological orientation to the study of memory. All of them believe that memory consists of separable but normally interacting processes and dissociable but normally collaborating systems and subsystems, and that an important research problem consists in the elucidation of the nature of these component processes and systems. Several authors also explicitly deal with the issue of consciousness and experience in memory and amnesia. All authors go much beyond the topics briefly covered in this introductory paper, treating memory and amnesia systematically from different vantage points.

Kinsbourne reviews some of the important facts and observations concerning the neuropsychology of amnesia, with special attention to the logic that relates such facts and observations to the current lively debate concerning multiple memory systems. Kinsbourne takes it as axiomatic that memory consists of separate but closely interacting systems. The issue of the logic that relates data to theory, and the "conceptual challenges provided by the extant (fragmentary) data" (this issue), is central to the debate, as the convergence of scientific opinion on the solution of the debate is necessarily predicated on the acceptance of comparable criteria in the assessment of the relevant evidence. If different workers adopt different kinds of logic, or even rely on idiosyncratic rules, the problem of multiple memory systems could not possibly be solved to everyone's satisfaction, even if all participants accept the same set of facts as relevant.

Weiskrantz provides an overview of the current knowledge concerning the neuroanatomy of memory and amnesia, as revealed by available data on correlations between impairments in behavioral and cognitive memory functions on the one hand and the nature of focal brain lesions on the other hand. He also, explicitly and forcefully, declares that memory is not "holistic" and that it consists of a number of normally interacting systems, each with a different anatomical base. Weiskrantz argues that continued neglect of multiplicity of memory systems will seriously hamper the efforts of making sense of rapidly accumulating data concerning memory and amnesia.

Schacter, after briefly highlighting the clinical syndrome of amnesia and contemporary neuropsychological research on it, presents a review of several kinds of experiments addressed to the currently highly critical problem: Can patients suffering from anterograde amnesia learn new *factual* knowledge? Reasonably good consensus exists that amnesics can learn new skills and that they cannot remember personal experiences; there is less agreement on the question concerning the learning of new facts and associations that Schacter addresses. Schacter's conclusion, that amnesics *can* acquire new factual knowledge, but that the rate of acquisition, and some other characteristics, are impaired, has implications for the debate concerning multiple memory systems.

Lister and Weingartner review the evidence on the effects of drugs on memory and other cognitive functions, emphasizing the complex nature of these functions. They distinguish between practical and theoretical concerns in neuropharmacological research on memory. For practical purposes it is often sufficient to know that a given drug has a certain effect on the overall performance on some memory task. The theoretical picture, however, is more complicated. Because of the large number of different component processes entailed in any memory performance, the fact that a drug may influence that performance is in and of itself not highly informative: The drug could have its effect on any one process or any combination of processes. To talk about the effect of a drug on "memory," from this point of view, is misleading.

Halgren and Smith describe their own and other investigators' research on the electrophysiology of learning and memory as revealed by scalp-recorded event-related potentials, although they also mention work with implanted electrodes. Students of electrophysiology of cognition now agree that short-latency components of these potentials reflect physical properties of presented stimuli, whereas the longer-latency, or endogenous, portions provide information about specific cognitive responses of the subject to these stimuli. Endogenous components of event-related potentials accompanying various perceptual, attentional, and immediate memory activities of normal human subjects have been successfully studied for some time now, but it is only recently that electrophysiological studies of longer-term memory processes have been undertaken in human subjects. In reviewing this work, Halgren and Smith discuss both the achievements to date and the methodological problems that confront researchers in this new and promising but difficult area of research.

Wood discusses the current state of the art in research concerned with the relation between memory and cerebral regional blood flow. Cerebral blood flow, as an index of neural activity in the brain, has been of interest to students of brain function for a long time. William James (1890, p 104), for instance, tells a charming story of the Italian physician Mosso's invention of the first "instrument" to measure blood flow in the brain. Mosso placed a person horizontally on a delicately balanced table that could tip down at either end. With the subject completely motionless, when the subject engaged in intellectual activity, Mosso reports, the table went down at the head-end. Today both science and technology are a bit more advanced. Instead of assessing the distribution of the blood between the head and the lower part of the torso, scientists now measure the distribution of the blood between different regions of the brain; instead of tilting tables, they use scintillation detectors and high-speed computers. Wood reviews the logic, problems, and findings of regional cerebral blood-flow research. The blood-flow data are intriguing, but their interpretation is not easy. Hence, at the present time, available evidence serves mostly to guide further research rather than to fill in the gaps in existing knowledge.

The work reviewed by all these authors show that we are making good progress. Even if the understanding of the puzzle of memory and the greater puzzle of consciousness still eludes us, we are closer to it now than we were 100 years ago when Ebbinghaus, James, Ribot, and Korsakoff, each in his own way, showed the world the way to the scientific study of some of Nature's most closely guarded secrets.

Author's note

The author's research is supported by the Natural Sciences and Engineering Research Council of Canada (Grant No. A8632) and by a Special Research Program Grant from the Connaught Fund, University of Toronto. Mrs. J. Law helped with library research and the preparation of the manuscript.

References

Anderson JR (1983) The architecture of cognition. Harvard University Press, Cambridge, MA

Anderson JR, Bower GH (1972) Recognition and retrieval processes in free recall. Psychol Rev 79:97–123

Anderson JR, Ross BH (1980) Evidence against a semantic-episodic distinction. J Exp Psychol [Human Learn Mem] 6:441–465

Atkinson RC, Shiffrin RM (1968) Human memory: a proposed system and its control processes. In: Spence KW, Spence JT (eds) The psychology of learning and motivation, vol. 2. Academic Press, New York, pp 89–105

Baddeley AD, Hitch G (1974) Working memory. In: Bower GH (ed) The psychology of learning and motivation, vol 8. Academic Press, New York, pp 47–89

Baddeley AD, Warrington EK (1970) Amnesia and the distinction between long- and short-term memory. J Verb Learn Verb Behav 9:176–189

Bjork EL, Healy AF (1974) Short-term order and item retention. J Verb Learn Verb Behav 13:80–97

Bjork RA (1975) Short-term storage: the ordered output of a central processor. In: Restle F, Shiffrin RM, Castellan NJ, Lindman HR, Pisoni DB (eds) Cognitive theory, vol. 1. Erlbaum, Hillsdale, NJ, pp 151–171

Broadbent DE (1958) Perception and communication. Pergamon, New York

Broadbent DE (1984) The Maltese cross: a new simplistic model for memory. Behav Brain Sci 7:55–94

Butters N, Lewis R, Cermak LS, Goodglass H (1973) Material-specific memory deficit in alcoholic Korsakoff patients. Neuropsychologia 11:291–299

Butters N, Wolfe J, Martone M, Granholm E, Cermak LS (1986) Memory disorders associated with Huntington's disease: verbal recall, verbal recognition and procedural memory. Neuropsychologia 23(6):729–743

Cermak L, Butters N (1972) The role of interference and encoding in the short-term memory deficits of Korsakoff patients. Neuropsychologia 10:89–95

Cermak L, Butters N, Gerrein J (1973) The extent of the verbal encoding ability of Korsakoff patients. Neuropsychologia 11:85–94

Claparede E (1911) Reconnaissance et moiite. Arch Psychol 11:79–90

Cofer C (1979) Human learning and memory. In: Hearst E (ed) The first century of experimental psychology. Erlbaum, Hillsdale, NJ, pp 323–369

Cohen NJ (1985) Levels of analysis in memory research: the neuropsychological approach. In: Weinberger NM, McGaugh JL, Lynch G (eds) Memory systems of the brain. Guilford Press, New York, pp 419 – 432
Cohen NJ, Squire LR (1980) Preserved learning and retention of pattern analyzing skill in amnesia: dissociation of knowing how and knowing that. Science 210:207 – 209
Corkin S (1968) Acquisition of motor skill after bilateral medial temporal-lobe excision. Neuropsychologia 6:255 – 265
Craik FIM (1970) The fate of primary memory items in free recall. J Verb Learn Verb Behav 9:143 – 148
Craik FIM, Jacoby LL (1975) A process view of short-term retention. In: Restle F, Shiffrin RM, Castellan NJ, Lindman HR, Pisoni DB (eds) Cognitive theory, vol. 1. Erlbaum, Hillsdale, NJ, pp 173 – 192
Craik FIM, Levy BA (1976) The concept of primary memory. In: Estes WK (ed) Handbook of learning and cognitive processes, vol. 4. Erlbaum, Hillsdale, NJ, pp 133 – 175
Craik FIM, Lockhart RS (1972) Levels of processing: a framework for memory research. J Verb Learn Verb Behav 11:671 – 684
Crowder RG (1986) Remembering experiences and the experience of remembering. Behav Brain Sci 9:566 – 567
Ebbinghaus H (1885) Über das Gedächtnis. Duncker und Humblot, Leipzig
Eich E (1984) Memory for unattended events: remembering with and without awareness. Mem Cogn 12:105 – 111
Estes WK (1976) The cognitive side of probability learning. Psychol Rev 83:37 – 64
Gaffan D (1985) Human and animal amnesia. In: Nilsson LG, Archer T (eds) Perspectives in learning and memory. Erlbaum, Hillsdale, NJ, pp 279 – 289
Glanzer M (1972) Storage mechanisms in recall. In: Bower GH, Spence JT (eds) The psychology of learning and motivation, vol. 5. Academic Press, New York, pp 129 – 193
Glisky EL, Schacter DL, Tulving E (1986) Computer learning by memory-impaired patients: Acquisition and retention of complex knowledge. Neuropsychologia 24:313 – 328
Gottlieb G (1979) Comparative psychology and ethology. In: Hearst E (ed) The first century of experimental psychology. Erlbaum, Hillsdale, NJ, pp 147 – 173
Graf P, Schacter DL (1985) Implicit and explicit memory for new associations in normal and amnesic subjects. J Exp Psychol [Learn Mem Cogn] 11:501 – 518
Hearst E (ed) (1979) The first century of experimental psychology. Erlbaum, Hillsdale, NJ
Herrmann DJ, McLaughlin JP (1973) Effects of experimental and preexperimental organization on recognition: evidence for two storage systems in long-term memory. J Exp Psychol 99:174 – 179
Hintzman DL (1978) The psychology of learning and memory. WH Freeman, San Francisco
Hintzman DL (1984) Episodic versus semantic memory: a distinction whose time has come – and gone? Behav Brain Sci 7:240 – 241
Hirsh R (1974) The hippocampus and contextual retrieval of information from memory: a theory. Behav Biol 12:421 – 444
Hirst W (1982) The amnesic syndrome: descriptions and explanations. Psychol Bull 91:435 – 460
Hirst W, Johnson MK, Kim JK, Phelps EA, Risse G, Volpe BT (1986) Recognition and recall in amnesics. J Exp Psychol [Learn Mem Cogn] 12:445 – 451
Hitch G (1985) Short-term memory and information processing in humans and animals: towards an integrating framework. In: Nilsson LG, Archer T (eds) Perspectives in learning and memory. Erlbaum, Hillsdale, NJ, pp 119 – 136
Huppert FA, Piercy M (1976) Recognition memory in amnesic patients: effects of temporal context and familiarity of material. Cortex 12:3 – 20
Ingvar DH (1985) Memory of the future: An essay on the temporal organization of conscious awareness. Human Neurobiol 4:127 – 136
Jacoby LL (1982) Knowing and remembering: some parallels in the behavior of Korsakoff patients and normals. In: Cermak LS (ed) Human memory and amnesia. Erlbaum, Hillsdale, NJ, pp 97 – 112
Jacoby LL, Witherspoon D (1982) Remembering without awareness. Can J Psychol 36:300 – 324
James W (1890) Principles of psychology. Holt, New York
Jenkins HM (1979) Animal learning and behavior theory. In: Hearst E (ed) The first century of experimental psychology. Erlbaum, Hillsdale, NJ, pp 177 – 228
Jones BM (1973) Memory impairment on the ascending and descending limbs of the blood alcohol curve. J Abnorm Psychol 82:24 – 32
Kihlstrom JF (1984) A fact is a fact is a fact. Behav Brain Sci 7:243 – 244
Kinsbourne (1986) Systematizing cognitive psychology. Behav Brain Sci 9:567
Kinsbourne M, Wood F (1975) Short-term memory processes and the amnesic syndrome. In: Deutsch D, Deutsch JA (eds) Short-term memory. Academic Press, New York, pp 258 – 291
Kinsbourne M, Wood F (1982) Theoretical considerations regarding the episodic-semantic memory distinctions. In: Cermak LS (ed) Human memory and amnesia. Erlbaum, Hillsdale, NJ, pp 195 – 217
Kintsch W (1970) Learning, memory, and conceptual process. Wiley, New York
Kolb B, Whishaw IQ (1985) Fundamentals of human neuropsychology, 2nd edn. WH Freeman, New York
Korsakoff SS (1889) Etude medico-psychologique sur une forme des maladies de la memoire. Rev Philosoph 5:501 – 530
Kuhn TS (1962) The structure of scientific revolutions. University of Chicago Press, Chicago
Lachman R, Naus M (1984) The episodic/semantic continuum in an evolved machine. Behav Brain Sci 7:244 – 246
Lashley KS (1929) Brain mechanisms and intelligence. Chicago University Press, Chicago
Lewis RS (1986) Variation on a theme: are the elements of episodic memory dissociable? Behav Brain Sci 9:567 – 568
Lockhart RS, Craik FIM, Jacoby LL (1976) Depth of processing, recognition and recall. In: Brown J (ed) Recall and recognition. Wiley, New York
Lynch G, McGaugh JL, Weinberger NM (eds) (1984) Neurobiology of learning and memory. Guilford Press, New York
Madigan SA, McCabe L (1971) Perfect recall and total forgetting: a problem for models of short-term memory. J Verb Learn Verb Behav 10:101 – 106
Mandler G (1980) Recognizing: the judgment of previous occurrence. Psychol Rev 87:252 – 271
Martone M, Butters N, Payne M, Becker JT, Sax DS (1984) Dissociations between skill learning and verbal recognition in amnesia and dementia. Arch Neurol 41:965 – 970
McKoon G, Ratcliff R, Dell GS (1986) A critical evaluation of the semantic-episodic distinction. J Exp Psychol [Learn Mem Cogn]12:295 – 306
Miller GA, Johnson-Laird PN (1976) Language and perception. Harvard University Press (Belknap Press), Cambridge, MA
Milner B (1958) Psychological defects produced by temporal lobe excision. In: Proceedings of the Association for Research in Nervous and Mental Disease, vol. 36: The brain and human behavior. Williams and Wilkins, Baltimore, pp 244 – 257
Milner B (1966) Amnesia following operation on the temporal lobes. In: Whitty CWM, Zangwill OL (eds) Amnesia. Butterworth, London, pp 109 – 133
Milner B (1970) Memory and the medial temporal regions of the brain. In: Pribram KH, Broadbent DE (eds) Biology of memory. Academic Press, New York, pp 29 – 50
Mishkin M, Malamut B, Bachevalier J (1984) Memories and habits: two neural systems. In: Lynch G, McGaugh JL, Weinberger NM (eds) The neurobiology of learning and memory. Guilford Press, New York, pp 65 – 77
Mishkin M, Petri HL (1984) Memories and habits: some implications for the analysis of learning and retention. In: Squire L, Butters N (eds) Neuropsychology of memory. Guilford Press, New York, pp 287 – 296.

Morris RGM (1985) Moving on from modeling amnesia. In: Weinberger NM, McGaugh JL, Lynch G (eds) (1985) Memory systems of the brain. Guilford Press, New York, pp 452 – 462

Moscovitch M (1982) Multiple dissociations of function in amnesia. In: Cermak LS (ed) Human memory and amnesia. Erlbaum, Hillsdale, NJ, pp 337 – 370

Neely JH, Durgunoglu AY (1985) Dissociative episodic and semantic priming effects in episodic recognition and lexical decision tasks. J Mem Lang 24:466 – 489

Nilsson L-G, Archer T (eds) (1985) Perspectives in learning and memory. Erlbaum, Hillsdale, NJ

Oakley DA (1980) Improved instrumental learning in neodecorticate rats. Physiol Behav 24:354 – 366

Oakley DA (1981) Brain mechanisms of mammalian memory. Br Med Bull 37:175 – 180

Oakley DA (1983) The varieties of memory: a phylogenetic approach. In: Mayes A (ed) Memory in humans and animals. Van Nostrand Reinhold, Wokingham, England, pp 20 – 82

Olton DS (1985a) Learning and memory: neural and ethological approaches to its classification. In: Nilsson L-G, Archer T (eds) Perspectives in learning and memory. Erlbaum, Hillsdale, NJ, pp 95 – 113

Olton DS (1985b) Strategies for the development of animal models of human memory impairments. In: Olton DS, Gamzu E, Corkin S (eds) Memory dysfunctions: an integration of animal and human research from preclinical and clinical perspectives. New York Academy of Sciences, New York, pp 113 – 121

Olton DS, Becker JT, Handelman GE (1979) Hippocampus, space and memory. Behav Brain Sci 2:313 – 365

Olton DS, Gamzu E, Corkin S (eds) (1985) Memory dysfunctions: an integration of animal and human research from preclinical and clinical perspectives. New York Academy of Sciences, New York. (Annals of the New York Academy of Sciences, vol. 444)

Parker ES, Weingartner H (1984) Retrograde facilitation of human memory by drugs. In: Weingartner H, Parker ES (eds), Memory consolidation: psychobiology of cognition. Erlbaum, Hillsdale, NJ, pp 231 – 251

Parkin AJ (1982) Residual learning capability in organic amnesia. Cortex 18:417 – 440

Pavlov I (1927) Conditioned reflexes. Oxford University Press, Oxford

Pribram KH (1984) Brain systems and cognitive learning processes. In: Roitblat HL, Bever TG, Terrace HS (eds) Animal cognition. Erlbaum, Hillsdale, NJ, pp 627 – 656

Quillian MR (1966) Semantic memory. Ph. D. dissertation, Carnegie Institute of Technology, Pittsburgh

Ratcliff R, McKoon G (1986) More on the distinction between episodic and semantic memories. J Exp Psychol [Learn Mem Cogn] 12: 312 – 313

Ribot T (1882) Diseases of memory. Appleton, New York

Roediger HL III (1984) Does current evidence from dissociation experiments favor the episodic/semantic distinction? Behav Brain Sci 7:252 – 254

Rosenzweig MR, Bennett EL (eds) (1976) Neural mechanisms of learning and memory. MIT Press, Cambridge, MA

Rozin P (1976) The psychobiological approach to human memory. In: Rosenzweig MR, Bennett EL (eds) Neural mechanisms of learning and memory. MIT Press, Cambridge, MA, pp 3 – 46

Schacter DL (1985) Priming of old and new knowledge in amnesic patients and normal subjects. In: Olton DS, Gamzu E, Corkin S (eds) Memory dysfunctions: an integration of animal and human research from preclinical and clinical perspectives. New York Academy of Sciences, New York, pp 41 – 53

Schacter DL, Moscovitch M (1974) Infants, amnesics, and dissociable memory systems. In: Moscovitch M (ed) Infant memory. Plenum, New York, pp 173 – 216

Schacter DL, Tulving E (1982) Memory, amnesia, and the episodic/semantic distinction. In: Isaacson RL, Spear NE (eds) Expression of knowledge. Plenum Press, New York, pp 33 – 65

Shallice T (1979) Neuropsychological research and the fractionation of memory systems. In: Nilsson L-G (ed) Perspectives in memory research. Erlbaum, Hillsdale, NJ, pp 257 – 277

Shiffrin RM (1975) Short-term store: the basis for a memory system. In: Restle F, Shiffrin RM, Castellan NJ, Lindman HR, Pisoni DB (eds) Cognitive theory, vol. 1. Erlbaum, Hillsdale, NJ, pp 193 – 218

Shoben EJ, Ross BH (1986) The crucial role of dissociations. Behav Brain Sci 9:568 – 569

Shoben EJ, Wescourt KT, Smith EE (1978) Sentence verification, sentence recognition and the semantic-episodic distinction. J Exp Psychol [Human Learn Mem] 4:304 – 317

Spear NE (1986) Conscious constraints on episodic memory. Behav Brain Sci 9:571 – 573

Squire LR (1982) The neuropsychology of human memory. Ann Rev Neurosci 5:241 – 273

Squire LR (1986) Mechanisms of memory. Science 232:1612 – 1619

Squire LR, Butters N (eds) (1984) Neuropsychology of memory. Guilford Press, New York

Squire LR, Zola-Morgan S (1985) The neuropsychology of memory: new links between humans and experimental animals. In: Olton DS, Gamzu E, Corkin S (eds) Memory dysfunctions: an integration of animal and human research from preclinical and clinical perspectives. New York Academy of Sciences, New York, pp 137 – 149

Thompson RF, Robinson DN (1979) Physiological psychology. In: Hearst E (ed) (1979) The first century of experimental psychology. Erlbaum, Hillsdale, NJ, pp 407 – 454

Thorndike EL (1898) Animal intelligence: an experimental study of the associative processes in animals. Psychol Monogr 2 (Whole No 8)

Tranel D, Damasio AR (1985) Knowledge without awareness: an autonomic index of facial recognition by prosopagnosics. Science 228:1453 – 1454

Tulving E (1972) Episodic and semantic memory. In: Tulving E, Donaldson W (eds) Organization of memory. Academic Press, New York, pp 381 – 403

Tulving E (1983) Elements of episodic memory. Oxford University Press, New York

Tulving E (1984a) Multiple learning and memory systems. In: Lagerspetz KMJ, Niemi P (eds) Psychology in the 1990's. Elsevier (North Holland), London, pp 163 – 184

Tulving E (1984b) Relations among components and processes of memory. Behav Brain Sci 7:257 – 268

Tulving E (1985a) How many memory systems are there? Am Psychol 40:385 – 398

Tulving E (1985b) Memory and consciousness. Can Psychol 26(1):1 – 12

Tulving E (1985c) On the classification problem in learning and memory. In: Nilsson L-G, Archer T (eds) Perspectives in learning and memory. Erlbaum, Hillsdale, NJ, pp 67 – 94

Tulving E (1986) What kind of a hypothesis is the distinction between episodic and semantic memory? J Exp Psychol [Learn Mem Cogn] 12:307 – 311

Tulving E, Bower GH (1974) The logic of memory representations. In: Bower GH (ed) The psychology of learning and motivation, vol. 8. Academic Press, New York, pp 265 – 301

Tulving E, Colotla V (1970) Free recall of trilingual lists. Cogn Psychol 1:86 – 98

Warrington EK (1979) Neuropsychological evidence for multiple memory systems. In: Brain and mind. Ciba Foundation Series 69. Elsevier North Holland, London

Warrington EK (1984) Category specific semantic impairments. Brain 107:829 – 854

Warrington EK, Weiskrantz L (1968a) A new method of testing of long-term retention with special reference to amnesic patients. Nature 217:972 – 974

Warrington EK, Weiskrantz L (1968b) A study of learning and retention in amnesic patients. Neuropsychologia 6:283 – 291

Warrington EK, Weiskrantz L (1970) Amnesia: consolidation or retrieval? Nature 228:628 – 630

Warrington EK, Weiskrantz L (1974) The effect of prior learning on subsequent retention in amnesic patients. Neuropsychologia 12:419 – 428

Warrington EK, Weiskrantz L (1982) Amnesia: a disconnection syndrome? Neuropsychologia 20:233 – 247

Watkins MJ, Kerkar SP (1985) Recall of a twice-presented item without recall of either presentation: generic memory for events. J Mem Lang 24:666 – 678

Waugh NC, Norman DA (1965) Primary memory. Psychol Rev 72:89 – 104

Weinberger NM, McGaugh JL, Lynch G (eds) (1985) Memory systems of the brain. Guilford Press, New York

Weiskrantz L (1968) Some traps and pontifications. In: Weiskrantz L (ed) Analysis of behavioral change. Harper and Rowe, New York

Weiskrantz L (1977) Trying to bridge some neuropsychological gaps between monkey and man. Br J Psychol 68:431 – 445

Wickelgren WA (1973) The long and short of memory. Psychol Bull 80:425 – 438

Wood F, Ebert V, Kinsbourne M (1982) The episodic-semantic memory distinction in memory and amnesia: clinical and experimental observations. In: Cermak LS (ed) Human memory and amnesia. Erlbaum, Hillsdale, NJ, pp 167 – 193

Wright AA, Santiago HC, Sands SF, Kendrick DF, Cook RG (1985) Memory processing of serial lists by pigeons, monkeys, and people. Science 229:287 – 289

Zola-Morgan S, Squire LR (1985) Medial temporal lesions in monkeys impair memory on a variety of tasks sensitive to human amnesia. Behav Neurosci 99:22 – 34