NEUROBEHAVIORAL RECOVERY FROM HEAD INJURY

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Memory Experiments: A Strategy for Research

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It is now widely accepted that even relatively mild head injury may, among other cognitive deficits, frequently result in impairment of memory functions (e.g., Brooks, 1984; Levin et al., 1982; Schacter and Crovitz, 1977). Problems of measurement of memory are, therefore, of considerable interest to neuropsychologists studying cognitive sequelae of head injury. Under the circumstances, one of the basic questions necessarily becomes, exactly what kinds of memory functions should we measure, and why?

Measurement of memory functions and their impairment is usually undertaken in two related situations. In one, memory performance of a group of selected patients is compared with that of a group of appropriate control patients, for the purpose of making general statements about the effects of brain damage on the intellectual functioning of the patients. When the distributions of scores of the two groups on a memory task differ reliably, the conclusion can be drawn that the memory function or functions tapped by the task are affected by the brain damage.[1]

In the other situation, the assessment of memory abilities of individual patients is of interest. Head-injury patients, not surprisingly, show large variations in the exact nature of injury that they have sustained, as well as the cognitive sequelae of these injuries. An accurate characterization of a given patient's cognitive functioning, and his or her pattern of memory performance, may be of considerable practical importance, especially when it is studied periodically, both *during* and *following* the clinically defined stage of posttraumatic amnesia. Such systematic assessment may be relevant not only to the problem of predicting the probable longer-term course of development of the cognitive consequences of injury, but also to matters such as the therapeutic management of patients, verification of patients' subjective reports of memory impairment or questionable claims of *no* impairment, and even the resolution of medicolegal disputes and litigation that may arise in certain situations.

Measurement of memory and memory impairment is fraught with difficulties in both situations. The major problems have to do with the lack of *adequate* measuring instruments, as well as the lack of basic information that would allow meaningful interpretation of the results of memory measurement. Most memory tasks that have been used by researchers to date possess only face validity, and their reliability is usually unknown. Moreover, information is seldom available concerning the "normal" range of individual differences in the performance of the tasks. The absence of alternate, equivalent forms of instruments is yet another handicap.

In many ways, the most serious source of difficulty in evaluating memory impairment of individual patients lies in the absence of information about their memory abilities from the period preceding their injury. In an ideal world, we would have available a record of each healthy individual's memory and cognitive abilities, as we now have available information about visual acuity, blood pressure, or cholesterol level. If the individual then suffers brain damage, it would be a simple matter of comparing his or her postinjury performance with that recorded before the injury. In the real world, practitioners can seldom do better than compare postinjury performance with some "normal" average, a procedure that is far from satisfactory.

Other difficulties reside in the unsystematic, atheoretical approach to measuring memory functions and their impairment that characterizes much of the extant literature. It is not unusual to see patients tested on a single task or on only a few tasks. These tasks, frequently psychometric tests, are thought to provide information about different kinds of memory functions, such as "verbal memory," "recognition memory," or "visual memory." The advantage of such tests lies primarily in their ready availability to the practitioner and their ease of administration. Their major shortcoming lies in their typically low reliability, and the unanalytical nature of the information they provide. For example, if the patient shows poor performance on a test for recall of words, but "normal" performance on a test of recognition memory for pictures, there is nothing much that can be done by way of interpreting such an outcome, other than restating the results: The patient's "verbal memory" or "recall memory for words" is impaired, whereas his or her "picture memory" is not. The conclusion implies that "verbal memory" is one entity, "picture memory" another, and that there are other such "memories," identified in terms of intuitively appreciated characteristics of relevant tests. In the absence of relevant empirical facts, the value of such conclusions is uncertain.

What can be done to improve the situation? The lack of extensive basic research and development of adequate and reliable instruments for measuring memory functions imposes considerable constraints on what can be done about some of the problems. Such basic research must be regarded as an item of high priority. Within the existing constraints, however, some modest ways of rationalizing the enterprise may also exist. In this paper, I present one proposal for systematizing the data-gathering activities in studies of memory impairment in head-injured patients.

The proposal is this: Instead of, or at least in addition to, assessing patients' memory functions by means of psychometric memory *tests*, miniature memory *experiments* could be conducted with the patients. A minimal experiment would consist of two conditions, and each patient would be tested in both. The two conditions would differ from each other with respect to values of a variable whose effect on the patients' performance could be interpreted as reflecting a particular component process of memory. The component processes thus studied would be selected to be meaningful within a theory of memory functioning.

I elaborate the proposal in the remainder of the paper.

MEMORY TESTS AND MEMORY EXPERIMENTS

Memory functions are ubiquitous: The daily life of human beings is highly dependent on the integrity of memory systems. Severe impairment of memory functions can be readily detected by external observers even if the afflicted person him- or herself remains unaware of the deficit. Subtler changes, however, require more careful and systematic observations than those made casually. Such observations are made under controlled conditions in situations referred to as *memory tasks;* they are expressed in quantitative terms. Memory tasks are administered to subjects either in memory "tests" or memory "experiments."

A *memory test* refers to a memory task in which *all* conditions—for example, the amount and nature of the to-be-remembered material, the mode and rate of presentation, and the retention interval—are held constant, and memory performance of a specific type is observed and quantified. An individual's performance on a test represents the joint effects of his or her abilities, skills, and knowledge on the one hand, and the particular properties of the test, on the other. There is no guarantee that the same individual will exhibit the observed level of ability on another test, even if the tests appear to tap rather similar functions. The differences among tests given to a patient are usually unsystematic: the tests are unrelated to one another.

In a *memory experiment,* one independent variable is manipulated while others are held constant. We can think of a memory experiment as consisting of two or more memory tests that differ from one another systematically, with respect to one dimension. A memory experiment, even a minimal one with only two conditions, allows patients to serve as their own controls. Comparison of the performance of an individual patient in different conditions of the experiment, therefore, enables us to relate observed performance differences to the component process of memory affected by the manipulated variable. In this sense, measurement of memory in an experiment represents a more analytical approach, and fits in better with current theoretical conceptualizations of memory.

These conceptualizations view memory *not* as a unitary entity, but rather as a set of *component processes.* This is true not only of memory in general, but also true of the particular "kinds" of memory that receive their names from the characteristics of the information being tested, such as "verbal memory" or "visual memory." The study of memory, according to this conceptualization, entails the analysis of a memory task into its constituent component processes, determining the conditions and variables that affect particular component processes, and integrating the component processes thus identified and characterized into the overall complex of a memory function.

The logic that helps us to plan research on memory functions in head-injured patients, or in any other group of brain-damaged patients, is this: A memory task consists of different components, different components reflect different underlying processes, and different underlying processes depend on the workings of particular brain mechanisms. Selective impairment of brain mechanisms, therefore, results in selective impairment of different components of a memory task. If a mechanism fails completely, the corresponding task component will also fail completely, unless alternative mechanisms exist that can substitute for the damaged ones. Consider a concrete example: If different events occur in a sequence, we may assume that one component process of remembering the sequence may entail knowing that a particular event occurred as a part of the sequence, whereas another may entail remembering the relative temporal date of the event. In this situation, it is possible to imagine that the component process responsible for temporal dating may be selectively impaired, whereas recall or recognition of the fact that an event has occurred may not be impaired, or may be impaired to a smaller extent.

There are different ways of classifying component processes of memory. One is in terms of different stages of remembering, stages such as encoding and retrieval; another is in terms of different memory systems, such as episodic and semantic memory. We will briefly consider them in turn.

ENCODING AND RETRIEVAL

Since about 1970, memory research in cognitive psychology has revealed that the two variables, *encoding operations* and *retrieval conditions*, and their interaction, are particularly effective for determining memory performance.

Encoding operations refer to the mental operations that the learners and rememberers perform on the to-be-remembered material at the time of study. These operations are experimentally manipulated in many ways. Thus, for instance, the subjects may be asked different questions about each to-be-remembered item, questions that focus on the rememberer's attention on certain aspects of the item (e.g., Craik and Tulving, 1975; Hyde and Jenkins, 1969; Schulman, 1974); alternatively, the to-be-remembered item may appear in a particular context a the time of study, a context that is likely to induce a particular format of encoding (e.g., Barclay et al., 1974; Thomson and Tulving, 1970; Tulving, 1968).

Many encoding experiments reported in the literature point to the overwhelming importance that encoding operations play in determining a person's memory performance (for a review, see Craik, 1981). When encoding operations are not controlled, as frequently happens in many memory experiments, and as almost always happens in memory tests (but see Buschke, 1984, 1986), a certain amount of variance observed in the subjects' performance is likely to

stem from the differences in covert encoding operations that the subjects have performed on the material. The important implication of such a state of affairs for the study of memory in head-injured patients lies in the possibility that the observed impairment in memory is attributable to impaired encoding operations rather than, or in addition to, other component processes of remembering. Miniature experiments, in which patients' memory performance is measured following different kinds of experimentally manipulated encoding operations, may provide potentially useful evidence as to the impairment of the encoding process (cf. Cermak and Reale, 1978). Such experiments are, therefore, recommended.

The most typical way of manipulating retrieval conditions consists of varying the *cues* that the rememberer is given at retrieval. In a free-recall test, no specific retrieval cues are provided; in cued-recall, the cues may consist of items preexperimentally or experimentally associated with to-be-remembered items; in recognition tests, the cues consist of nominal copies of to-be-remembered items. In other retrieval conditions, the pharmacological state of the subject (e.g., Eich et al., 1975), or the physical environment (e.g., Smith et al., 1975; Winocur and Kinsbourne, 1978) may be varied. The experimental literature is full of accounts of large differences in memory performance depending on retrieval conditions (for a review, see Craik, 1981). The implications for the study of memory functions in head-injured patients is again clear: experiments in which retrieval cues are systematically manipulated may provide useful information concerning the process of retrieval and its possible deficiencies (cf. Cermak and Stiassny, 1982).

Let us now turn to episodic and semantic memory.

EPISODIC AND SEMANTIC MEMORY

The distinction between episodic and semantic memory is a part of a larger classificatory scheme in which memory is divided into subsystems. One such classification that is now widely accepted concerns the division between short-term and long-term memory. It is reasonable to think of this division as representing different neurocognitive systems: it is known that the brain mechanisms subserving long-term memory functions can be selectively impaired without concomitant impairment of short-term memory functions (e.g., Baddeley and Warrington, 1970; Moscovitch, 1984).

The distinction between episodic and semantic memory can be viewed as a part of a broader classificatory system that also includes procedural memory. As this latter form is discussed by Baddeley and colleagues (Chapter 20, this volume), I will consider only episodic and semantic memory.

Semantic memory refers to an organism's ability to acquire, retain, and use general knowledge of the world that it shares with other members of the species. *Episodic memory* transcends semantic memory by also making it possible for an individual to remember his or her own past.

The encoding and retrieval experiments that I discussed earlier could, roughly speaking, be said to be concerned with episodic memory: the subjects' task is to remember particular items that occurred in a particular list. Yet it is clear that the subjects' semantic memory also plays an important role in determining the outcome of the experiment. In the encoding experiment, for instance, the kind of memory trace that is stored about each item depends on the encoding operation in which the knowledge of the world that the subject has is brought to bear upon the to-be-remembered item; in the retrieval experiment, the subject must necessarily interpret the retrieval cue in terms of his or her semantic knowledge. In general, it seems a reasonable hypothesis that different episodic-memory tasks vary with respect to the extent to which episodic and semantic processes are necessary for the successful carrying out of the task.

A fuller discussion of the properties of episodic and semantic memory, and their relation to each other, as well as to procedural memory, can be found elsewhere (Tulving, 1983, 1984, 1985a, 1985b). Let me briefly summarize the distinction here, however, because it is relevant to what follows later.

Semantic memory enables organisms to represent states of the world that are perceptually absent, in the form of "mental models" (Craik, 1943; Johnson-Laird, 1983; Yates, 1985) that can be operated on covertly, in the absence of any overt behavior. Semantic memory differs from procedural memory in that its information can be acquired through observation alone; it describes the world, without prescribing any necessary action. Any given bit of semantic-memory knowledge can be expressed symbolically and in different forms. Semantic-memory operations, such as encoding and retrieval, require a higher level of consciousness than that entailed in procedural memory. This higher level of consciousness can be referred to as *noetic* (knowing) *consciousness* (Tulving, 1985b).

Episodic memory *adds* to the semantic memory capabilities the ability to keep track of the past and to imagine the future. Thus, episodic memory has to do with the individual's personal identity as it exists in subjective time. Whereas people *know* the world, they *remember* their own past. Remembering of personally experienced events requires the highest form of consciousness, called *autonoetic* (self-knowing) *consciousness* (Tulving, 1985b) Autonoetic consciousness is responsible for the familiar phenomenal flavor of remembering, with its feeling of pastness and belief in the veridicality of what is being remembered. In severe amnesia, such feeling and belief is lost.

The ontological status of episodic and semantic memory is being hotly debated at the present time. Many memory researchers believe that the distinction between procedural memory on the one hand, and the other two kinds on the other, is neurophysiologically real (e.g., Baddeley, 1984; Cohen and Squire, 1980; Squire and Cohen, 1984), but that the division between episodic and semantic memory represents nothing more than a convenient, albeit frequently useful, classificatory device (e.g., Anderson and Ross, 1980; Kihlstrom, 1984; Lachman and Naus, 1984; McKoon et al., 1986). Other researchers, however, are more willing to contemplate the possibility that episodic and semantic memory represent different, albeit closely related, neurocognitive systems (e.g., Cermak, 1984; Kinsbourne and Wood, 1975; Lewis, in press; Seamon, 1984, Tulving; 1983, 1985a; Wood et al. 1982). Regardless of the eventual out-

come of this debate, the tentative acceptance of the distinction between episodic and semantic memory may help to focus research concerning cognitive sequelae of head injury on theoretically fruitful issues.

Hypothetically, the relation between episodic and semantic memory is such that episodic memory is highly dependent on semantic memory for successful operations, whereas semantic memory can operate inependently of episodic memory (Tulving, 1985a). The same relation may apply to memory tasks and their component processes. If so, we can assume that if Task A depends more heavily on episodic memory processes than Task B, then damage to the neural mechanisms subserving episodic memory should affect performance on Task A more severely than performance on Task B. This general logic, even if applied to a hypothetical state of affairs in the nervous system, may be used in planning systematic experiments with head-injured patients. Let me give two simple illustrations of the kind of experiments that might be useful.

The first illustrative experiment consists of presenting to the subject a set of items (words, pictures, or whatnot), and imposing different retrieval requirements in the two conditions of the experiment. In one condition, the subject is required to make a judgment as to whether or not he or she remembers seeing the test item in the study list; in the second, the subject is required to make the *additional* judgment as to exactly when the item appeared (e.g., early or late in the list, before or after another recognized item). Now the second condition entails the first, but goes beyond it in requiring processing of the kind that uniquely characterizes episodic memory. To the extent that brain damage, whether diffuse or focal, has impaired the episodic system more severely than the semantic system, we would expect to observe a dissociation of the two tasks: a more severe impairment of the temporal dating judgments than the recognition judgments. This kind of outcome has in fact been reported by Huppert and Piercy (1976) and by Hirst and Volpe (1982). Moreover, given the logic of the situation, we might even expect that a double dissociation is less likely in this situation: There should be fewer or perhaps even no cases of brain damage that result in impairment of simple recognition while leaving temporal dating ability intact.

MEMORY PERFORMANCE AND CONSCIOUSNESS

As background for our second illustrative example, consider the dissociation between behavior and consciousness that is sometimes observed in memory tasks. It is now well established that amnesic patients sometimes show evidence of having acquired information in an experimental task, without knowing that they have done so and without remembering the learning episode.

Thus, in an experimental paradigm made famous by Warrington and Weiskrantz (1970, 1974), amnesic patients could complete graphemic stems of previously studied words (e.g., *ste—* for "steel," *bri—* for "bride") just as well as control subjects, even though the amnesics' recognition memory for the same words is very much poorer than that of the controls. If the word stems are presented to the subjects as retrieval cues for the *recall* of words from the list, the subjects may well ask, "What list?", not remembering having seen any list—as happened in the Warrington and Weiskrantz experiments. However, when urged by the experimenter to go ahead anyway, they can produce a fair number of list words. If the experimenter considers the patients' word-responses alone, the conclusion would be justified that the amnesics' performance on a stem-cued recall task is not impaired. If, on the other hand, the state of the patients' consciousness, as revealed in their "commentary" (Weiskrantz, 1978), is taken into account, the conclusion would have to be that amnesics perform poorly on the episodic cued *recall* task and that what appears to be episodic recall may reflect the operation of some other memory systems (Tulving, 1983, Ch. 6). The lesson to be learned from this example is that sometimes just looking at the products of an individual's memory is not enough.

A slightly different sort of dissociation between conscious awareness and overt behavior is seen in a phenomenon referred to as *source amnesia* (Evans and Thorn, 1966), in which a person recalls a bit of recently acquired information but cannot recall where or when he or she picked it up. The phenomenon is known to everyone: It frequently happens that after some time we do not know any more where or how we acquired the knowledge that we have, even though we do know it shortly after the learning episode. Amnesic patients, on the other hand, may exhibit source amnesia only a few *seconds* after learning (e.g., Schacter et al., 1984).

We are now ready to consider the second kind of illustrative experiment. It is like the experiment reported by Schacter et al. (1984). Patients are first exposed to information from different sources (e.g., different speakers who are present, or who have distinctive recorded voices) and are subsequently tested for both (1) just the information gained, and (2) the source of the acquired and known information. The processing requirements are more severe in the latter test than in the former, and we can apply the same reasoning to this experiment that we applied to the comparison of recognition and temporal dating judgments. As a consequence, we would expect (1) that the memory deficit concerning the source would occur more frequently than would the impairment of memory for the newly acquired information itself, and (2) that fewer cases of brain damage would be found in which memory for the source is intact while that for the acquired information is not. Empirical tests of these expectations, of course, require careful control and elimination, or assessment, of possible confoundings, but these are technical problems that should not present insurmountable difficulties.

CONCLUSION

In this paper I have recommended that miniature experiments be conducted with head-injured patients whose memory functions are of interest. In a minimal experiment, each patient's memory performance is assessed in two tasks that differ systematically from each other. The tasks, and the manipulated variables, are to be selected on theoretical grounds, with a view to justifying conclusions regarding particular component processes of memory functions. I

have presented illustrative examples of such experiments, based on theoretical distinctions between encoding and retrieval processes, and between episodic and semantic memory.

Doing miniature memory experiments with head-injured patients, instead of testing them with unrelated tests, and interpreting the findings of such experiments within a more general framework such as encoding and retrieval processes, or episodic and semantic memory, is by no means a universal panacea. It is only one among several steps that could be taken at the present time to systematize research and to tie it more closely to theory. However, taking the step entails few risks. It is difficult to see how the approach I have advocated would be *less* useful than the currently prevalent atheoretical approach. Even if the thoughts guiding the proposal turn out to be wrong, or incomplete, the systematic nature of research conducted under their aegis remains.

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NOTES

1. In the comparison of a group of patients with their controls, the typical practice is to consider measures of central tendency only, usually the means. It may be frequently useful, however, to examine the shapes of the two distributions of scores as well. The interpretation of the results may be different in a situation in which the *whole* distribution of the patients' scores on the task under scrutiny is shifted relative to that of the controls, from the interpretation in a situation in which, say, the distributions differ primarily at the low end of the scores.

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