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On the Transfer of Information from Temporary to Permanent Memory [and Discussion]

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On the transfer of information from temporary to permanent memory

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The idea that information is transferred from temporary to permanent storage is a pervasive one in memory research. However, in this article it is argued that the idea is unnecessary and misleading. Functions relating rehearsal time to subsequent memory performance take a variety of forms, depending first on the qualitative nature of the encoding processes carried out during rehearsal, and second on the compatibility of retrieval processes with the initial encoding. It is argued that memory is largely a function of depth and elaboration of the initial encoding, and that the memory deficits found in elderly people and under conditions of divided attention reflect impaired comprehension of the material. On the other hand, amnesic patients exhibit adequate comprehension yet poor memory, suggesting that some physiological process of consolidation may also be involved in normal learning and remembering.

The notion that information is transferred from one location to another within the memory system is at first sight an eminently reasonable one. It is well established that various characteristics of an encoded event can be stored in memory and that these qualitatively different aspects persist for very different times. Thus, shortly after a written word has been perceived in the course of normal reading, its visual characteristics are apparently registered in a transient iconic memory, its phonemic characteristics are held in a temporary working memory or short-term store, and its semantic characteristics are held in a relatively permanent long-term memory system. Many experimental psychologists have identified these different kinds of memory with discrete memory 'stores'. In the late 1960s, for example, it was generally accepted that incoming information was first registered in a modality-specific sensory store (e.g. iconic or echoic memory) and that these sensory registers preceded the mechanisms of selective attention. If the event was selected for further processing, information was then transferred by the processes of attention to a common, limited-capacity, short-term store. From there (if the task or material warranted further action), information about the event was transferred to a semi-permanent, long-term store by the processes of rehearsal and learning. This general account, drawn from several theorists, was described by Murdock (1967) as the 'modal model'. Within this framework, the researcher's task was to elucidate the properties of the various stores (e.g. capacity, coding characteristics and forgetting functions) and the properties of the processes that transferred information between them. The model seemed particularly appropriate for establishing links between psychology on the one hand and neurophysiology and neuro-anatomy on the other, in that memory stores and transfer functions might be identified as specific brain structures and processes.

The concept of information transfer between the short-term store (STS) and long-term storage (LTS) was further developed in the influential model proposed by Atkinson & Shiffrin (1968).

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In this model, STS contains a flexible 'rehearsal buffer', which can hold up to four or five items. Information about each item (usually words in the experiments conducted to test the model) is transferred to LTS as a direct function of its length of stay in the buffer and as an inverse function of the number of items sharing space in the buffer. These notions provide a good account of the primacy and recency effects in the free recall serial position curve. The very first word presented occupies the whole buffer; much information is therefore transferred about it to LTS. When the second word is presented, the buffer splits into two 'slots', further information is transferred about the first word (but now at a slower rate), and information relevant to the second word is also transferred. This process continues until four items have been presented. When the fifth item is presented, the buffer cannot divide further and so the first-presented item is now dropped to make way for the fifth, and each succeeding item similarly pushes previous items down one slot. The primacy effect thus reflects the greater amount of information transferred about the first few items; the recency effect reflects the fact that immediately after list presentation the last four or five items are still held in the buffer, with some probability, and are thus relatively easily retrieved. Items in the middle of the list are in the buffer for equivalent times, and this is reflected in the flat middle portion of the serial position curve. The model also accounts well for the finding of negative recency in a final recall test of all lists (Craik 1970). That is, words at the end of each list (especially the very last word) are held in the buffer for *less* time than items in the middle of the list because they are recalled very shortly after presentation: the reduced transfer time is well reflected in poorer final recall of these terminal items.

Atkinson & Shiffrin (1968) presented a sophisticated mathematical model to specify the various parameters of the rehearsal buffer, including r, the number of slots, and θ, the transfer rate from the buffer to LTS. The overall model provided an extremely useful heuristic framework for the study of memory, and greatly enhanced the plausibility and reasonableness of 'box models' by specifying more exactly how the system might work. In fact, whereas earlier information-processing models had focused largely on the structural components of the system – the memory stores – the Atkinson & Shiffrin model allowed processes to play a much larger part, although structural aspects were much less clearly specified. It is unclear, for example, what role the structure of STS plays apart from that of a hypothetical casing for the rehearsal buffer; the rehearsal processes themselves are sufficient to account for the phenomena. Later models (e.g. those due to Atkinson & Shiffrin (1971), Craik & Lockhart (1972), Kolers (1973) and Murdock (1982)) have continued the trend to model the memory system in terms of processes and operations rather than as structures and mechanisms.

Despite its usefulness, however, the buffer model has its failings, some of which are sufficiently serious to warrant its rejection, in my view. First, although the notion of transfer is central to the model's account of how an encoded event is stored permanently, very little is said about what is happening during the transfer operation. Just how does a word encoded phonemically in STS get transformed into a semantically encoded item in LTS: what exactly is 'transferred'? It seems more reasonable (indeed, necessary) to assume that the word's meaning is already represented in LTS and that transfer may involve the activation (priming? tagging?) of that representation (see, for example, Anderson & Bower 1973; Shiffrin 1976). But if this is a preferable account, why should the item's elicitation depend so systematically on time in the buffer and on the number of other items sharing space in the buffer?

A more central concern is that whereas the Atkinson & Shiffrin model assumes that rehearsal or transfer is essentially of one type, later experimental work has clearly demonstrated that rehearsal varies in its qualitative nature and that subsequent memory for the event depends strongly on the type of rehearsal activity performed (Craik & Lockhart 1972; Craik & Tulving 1975; Jacoby 1973; Mandler 1979; Woodward *et al.* 1973). In general, rote rehearsal of the sensory or 'surface' aspects of a word or other event is associated with poor retention, whereas rehearsal of the semantic aspects and implications of the event is associated with good retention. Craik & Lockhart (1972) argued that retention reflects the 'depth of processing' that an item achieves, where greater depth refers to greater degrees of semantic involvement; early 'shallow' analyses of the item are concerned with such stimulus qualities as brightness, loudness and shape, whereas later 'deeper' analyses are more concerned with the significance of the item in terms of the subject's past experience. In their 1972 article, Craik & Lockhart talked about levels of analysis, implying a sequence of analytic stages running from sensory to semantic–associative; however, later versions of the depth-of-processing ideas (e.g. Craik & Jacoby 1979) have endorsed current notions of interactive processing (that is, a mixture of stimulus driven 'bottom-up' processing and conceptually driven 'top-down' processing, Rumelhart 1977). In any event, the central idea is that memory is not a separate faculty in any sense, but is a reflection of processing carried our primarily for the purposes of perception and comprehension, with certain types of processing (typically, richer, more elaborate, and more meaningful encodings) being associated with higher levels of retention. Correspondingly, this set of notions leads to the prediction that poor memory should often be associated with poorer initial comprehension of the event ('often' rather than 'inevitably' because other factors, such as retention interval, similarity of the event to others recently experienced, and adequacy of the retrieval information provided, undoubtedly also play a part).

Whereas the Atkinson & Shiffrin model claimed that simple time in the buffer (plus the degree to which other items shared the available space) was sufficient to predict registration in LTS, the levels-of-processing view proposed that the qualitative type of processing was the crucial determinant of subsequent retention. Both Craik & Lockhart (1972) and Bjork and his colleagues (e.g. Woodward *et al.* 1973) suggested that rehearsal could usefully be broken down into two types, first a rote activity 'maintenance rehearsal', whose function was largely to maintain the activity of recently presented items in conscious awareness, and second, 'elaborative rehearsal': a set of cognitive activities involving further processing of the item, especially further processing of a semantic–associative nature. By the levels-of-processing view, only rehearsal of the second type should lead to an improvement in memory performance (because a deeper encoding is formed) and this prediction was confirmed by Craik & Watkins (1973) and by Woodward *et al.* (1973). However, it has also been shown that although maintenance rehearsal does not improve subsequent recall, it does serve to improve subsequent recognition memory (Glenberg *et al.* 1977; Woodward *et al.* 1973). Thus both the type of encoding and the type of retrieval must be considered in order to understand the overall pattern of results.

The conclusion that encoding and retrieval tasks interact is strengthened by the results of a study by Geiselman & Bjork (1980). In this experiment, subjects rehearsed groups of three words for 5, 10 or 15 s. During the rehearsal interval they either simply repeated the words in a rote fashion (primary rehearsal in their terms) or attempted to construct meaningful connections among the three words by forming a sentence, for example (secondary rehearsal). A further important feature of the study was that subjects were first familiarized with a

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particular speaker's voice and conducted all their rehearsal activities in that (mimicked) voice. At test, words were presented for recognition either by the mimicked voice (thereby equating the surface characteristics of encoding and retrieval operations) or by a different speaker. The results are illustrated in figure 1. They show that primary rehearsal time was associated with an improvement in recognition memory only when the test words were spoken in the mimicked voice. For secondary rehearsal, longer rehearsal durations were associated with higher levels of recognition regardless of the voice used at test. This pattern of results can be construed as showing that the rehearsal interval provides time that is more or less sufficient for the formation of a particular encoded representation. Recognition performance thus depends both on the qualitative nature of the encoding and on the similarity of test operations to encoding operations (Fisher & Craik 1977; Tulving & Thomson 1973). One interesting feature of figure 1 is that

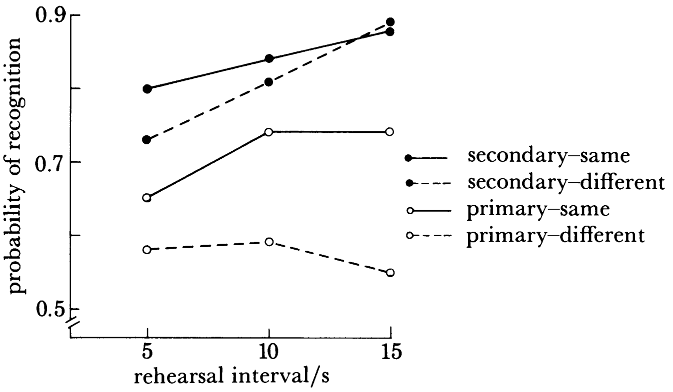

FIGURE 1. Probability of word recognition as a function of type of rehearsal (secondary = elaborative; primary = maintenance), compatibility between encoding and retrieval, and rehearsal interval. (Geiselman & Bjork (1980).)

recognition performance does not increase beyond the 5 s rehearsal interval for the 'primary–different' condition; it increases from 5 to 10 s, but thereafter shows no further improvement for 'primary–same'; but recognition continues to improve from 5 to 15 s for both elaborative (secondary) conditions. Speculatively, different codes require different lengths of time to be formed, but once they are formed further rehearsal time confers no further benefit. For the same material, deeper codes may require longer rehearsal durations, but very compatible materials (e.g. pictures, salient exemplars of semantic categories) may well be encoded very rapidly (Craik & Lockhart 1972).

Further patterns of rehearsal will be considered later in this article, after a consideration of retrieval operations. For the moment I wish to emphasize that the same rehearsal duration can be associated with very different levels of subsequent retention, and that these well documented empirical effects necessitate the rejection of Atkinson & Shiffrin's rehearsal buffer model, at least in its original form. In contrast to the notion that retention or rehearsal serve to transfer information to another location, my own claim is that retention reflects the qualitative type of representation formed, with more elaborate, semantic representations being in general associated with higher levels of retention. Most usually, in day-to-day activities, the final representation will be formed more or less immediately at the time of perception or initial comprehension. In situations involving learning, further rehearsal or repetitions of the event will enhance retention by allowing the formation of a more adequate encoding, but in all cases

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it is the qualitative nature of the final representation that determines retention, rather than the quantitative 'amount' of information that has been transferred to permanent storage. As a final point in this section, although I have described two categories of rehearsal – maintenance and elaborative – it seems to me more likely that a large variety of different rehearsal types exists, from operations that simply repeat the sounds of words, for example, to operations concerned with constructing images, inferences and implications (Craik & Jacoby 1979).

Retrieval processes

An account of memory in terms of traces deposited in stores leads naturally to the idea that retrieval must consist of a search through the store until the wanted trace is located. An alternative, more dynamic, account of memory storage departs from the basic assumption that perceived events are preserved as intact discrete records or traces and suggests instead that the whole cognitive system is subtly altered by the initial experience and that the system has an increased likelihood of recreating the same pattern of activity on a subsequent occasion, especially if many aspects of the original event are re-presented to help drive the system into the same general configuration. This view of encoding as a widely distributed change in the system's *potential* to respond in a given way is at least compatible with Lashley's (1930) classic experiments showing that memories are represented diffusely in the brain; it is also compatible with the view that remembering is an activity, similar in many ways to perceiving and thinking (Bartlett 1932; Bransford *et al.* 1977; Kolers 1973).

By this account, retrieval processes are not seen as a 'search' for a wanted trace, but as a reinstatement of the original encoding operations (Kolers 1973). The phenomenal feeling of 'remembering' rather than 'perceiving' may be a function of the mismatch between the remembered initial context and the present context (M. Kinsbourne, personal communication). In this scheme, retrieval operations are seen as being very similar to encoding operations, and may therefore be similarly characterized in terms of qualitative types (e.g. depth or elaboration). Just as a particular encoding operation will be associated with different levels of retention depending on how closely the retrieval operations match the original encoding operations, so different retrieval tasks or cues will be differentially effective as a function of the compatibility between the operations induced by the task or cue and the operations performed during encoding. This basic idea is captured both by Tulving's notion of encoding specificity (Tulving & Thomson 1973) and by Kolers's proposal that recognition memory involves repetition of pattern-analysing operations (Kolers 1973, 1979). Perhaps its major importance is the implication that memory cannot be thought of as more or less of some thing (e.g. the idea that memories vary in 'strength'); rather, memory performance is necessarily relative: an interaction between encoding and retrieval (Tulving 1979). This account becomes more obvious if perceiving and remembering are described in the same terms; it is immediately clear that percepts vary qualitatively not quantitatively, and the present proposal is that remembering and perceiving are essentially similar. Both should be thought of as mental activities, as opposed to mental objects or contents, and both reflect interactions between incoming information ('stimulus patterns' or 'retrieval cues') and the mental representations of the organism's accumulated past experiences.

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Empirical illustrations

Once it is acknowledged that memory performance will depend on the qualitative type of encoding achieved and the compatibility between encoding and retrieval operations, the functions linking rehearsal time to subsequent retention levels become much more complex. The idea that long-term retention is simply a function of time in the buffer (Atkinson & Shiffrin 1968) or of the 'total time' studied (Cooper & Pantle 1967) must be rejected as capturing only one aspect of the situation, at best. Figure 2 shows some theoretically possible outcomes relating rehearsal time to retention level. In each case the retention levels associated with two qualitative types of rehearsal activity – rote and elaborative – are contrasted. The point I wish to stress is that even when both rehearsal time and qualitative type of encoding are taken into consideration, the final retention levels observed will depend on other factors also: principally the type of retrieval task given or retrieval information provided.

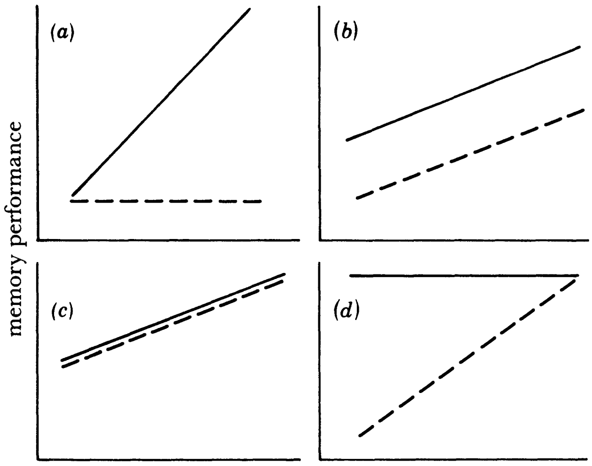

Figure 2. Theoretically possible functions relating rehearsal time to memory performance. Encoding: ——, good; ---, poor.

The very different functional patterns shown in figure 2 have in fact been found in various experiments. Figure 2*a* suggests that rehearsal time is differentially beneficial for elaborative and for rote rehearsal, and this is illustrated in the comparison between secondary–different and primary–different in figure 1. This pattern is also found when free recall is the method of testing: maintenance or rote rehearsal has no facilitating effect but elaborative rehearsal does. Mandler (1979) has suggested that recall depends crucially on the formation of inter-item associative connections and that elaborative rehearsal serves to construct such encodings. Thus the rehearsal interval allows the construction of certain types of representation, but it does not seem useful to describe these constructive operations as 'transfer' of information. Figure 2*b* shows that pattern obtained by several workers when the test of retention is recognition memory. To some extent this pattern is also seen in figure 1, by comparing secondary–same with primary–same; it was also reported by Glenberg *et al.* (1977) and by Woodward *et al.* (1973). Although elaborative rehearsal is associated with superior recognition performance, longer periods of maintenance rehearsal lead to the formation of greater degrees of intra-item integration (Mandler 1979) or perhaps to greater degrees of association between the item and

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its 'general situational context' (Woodward *et al.* 1973) or to enhanced auditory or articulatory encoding (Glenberg & Adams 1978). Whichever type or types of information are enhanced, the further encoding operations can apparently be used effectively at the time of the recognition test.

Figure 2*c* shows the case in which elaborative encoding confers no benefit over rote rehearsal for later retention. This general pattern was reported by Jacoby & Dallas (1981) in an experiment involving perceptual identification of previously presented words as the test of retention. In the first phase of the study, subjects were induced to encode words shallowly or deeply by means of orienting tasks; this differential treatment at the time of encoding is typically associated with large differences in subsequent recall and recognition (Craik & Tulving 1975). This result was also found by Jacoby & Dallas, but when single words were exposed briefly on a tachistoscope for subjects to identify, the researchers found that subjects had a higher probability of identifying words from the first phase than they had of identifying 'new' words, but that the type of processing received by the words in phase I had no differential effect on identification. Plausibly, the type of information used by the perceptual identification task is relatively low-level (orthographic?), and this information is encoded equally in phase I, regardless of the depth of processing induced. Interestingly, further repetitions of a word in phase I was associated with higher levels of perceptual identification in phase II, so the relevant information can be enhanced.

The general point that different types of information are relevant to different retention tests was elegantly demonstrated in a further study by Jacoby (1983*a*). In this experiment, phase I consisted of a subject's reading aloud or generating a series of visually presented words under three experimental conditions. In the 'no context' condition, the word to be read was preceded by a row of x's, which therefore gave no information about the word; in the 'context' condition, the word was always preceded by its antonym and thus the subject was primed to expect the subsequent word; in the 'generate' condition, the antonym was presented first but was then followed by a row of question marks, and the subject's task was to generate the target word (see table 1). By this procedure Jacoby carefully varied the amounts of orthographic and semantic processing required to carry out the task in phase I. That is, the first condition requires the greatest amount of orthographic processing of the target word (because no prior expectation is possible) but also requires relatively little semantic processing; the second condition requires less orthographic analysis (because the target word has been 'primed' by the preceding antonym) but correspondingly involves more semantic processing; finally, the 'generate' condition involves essentially no orthographic processing (because the target word is never presented visually) but requires the greatest amount of semantic processing. After phase I, subjects were given either a recognition memory test, or the perceptual identification task. As table 1 shows, recognition memory increased from 'no context' to 'generate' whereas perceptual identification shows exactly the opposite pattern of results. This experiment again demonstrates that the qualitative nature of both the encoding task and the test of retention must be considered if the pattern of results obtained is to be understood.

Figure 2*d* shows a hypothetical situation in which further rehearsal time confers no further benefit on the elaborate encoding but does serve to increase performance for rote rehearsal. This pattern may not be found with different encoding operations on the same material (indeed, it was suggested previously that more elaborate codes typically take more time to construct), but may be found across materials or across different groups of subjects. Thus a short rehearsal

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TABLE 1. PROBABILITY OF RECOGNITION AND IDENTIFICATION IN THREE EXPERIMENTAL CONDITIONS (JACOBY 1983)

	experimental condition		
	no context	context	generate
procedure	xxxxxx 'cold'	hot 'cold'	hot ???
recog. memory	0.56	0.72	0.78
percept. ident.	0.82	0.76	0.67

interval may suffice for a group of efficient encoders, with further time giving no further benefit, whereas a less efficient group may take a longer time to achieve an equivalent encoding. This pattern is seen in a paired-associate study involving young and older adults conducted by Treat & Reese (1976). The mean age of the young group was 29 years and the mean for the old group was 69. Subjects were given ten word pairs to learn; the test consisted of presenting the first word (stimulus) from each pair with the subject's task being to recall the corresponding second word (response). In the conditions to be discussed here, subjects were given either no specific instructions about learning the words (control), or were instructed to form an interacting image of the two items in each pair (imagery). The timing of the trials was also varied: in one condition the stimulus word was presented alone for 2 s, the stimulus and response words were then presented together for 2 s, and finally there was an interpair interval of 6 s (2–2–6 condition). In a second condition (2–6–2) these times were 2 s, 6 s and 2 s respectively, and in a third condition (6–2–2) the times were 6 s, 2 s and 2 s respectively. It is reasonable to suggest that these conditions become easier from 2–2–6 to 2–6–2 to 6–2–2 because, although the total time remains constant, the subjects must produce the correct response word during the first interval (6 s in the third condition as opposed to 2 s in the first two conditions), and the words were present for a total of 8 s in the last two conditions, but only for a total of 4 s in the first condition.

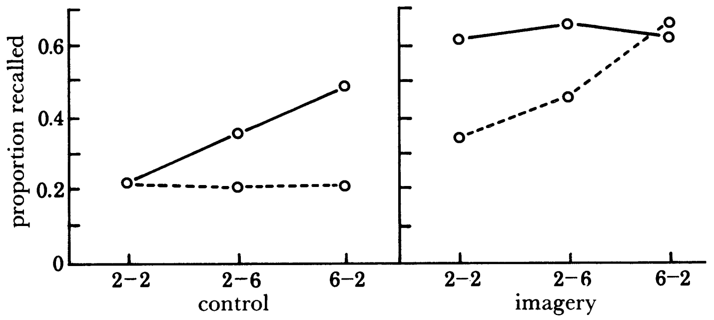

FIGURE 3. Proportions of words recalled by young (——) and old (---) subjects as a function of instructions and conditions. (Treat & Reese (1976).)

The results are shown in figure 3. They demonstrate that as learning and response times increase in the control condition, the young subjects recall more, but the old fail to benefit. This pattern mimics figure 2*a* and suggests that despite the extra time, the older subjects fail to carry out further beneficial operations – plausibly they simply persist in rote rehearsal. The younger subjects do benefit, however, and may thus be engaging spontaneously in more effective encoding or retrieval operations with the increase in time. The imagery condition yields a different pattern, and resembles figure 2*d*. Now the old subjects do benefit from the easier conditions but the young do not, even though they are clearly not at ceiling. My suggestion is that the younger subjects are able to construct an effective image in the 2–2–6 condition and thus do no further useful processing when the time constraints are less severe. However, the older subjects require both strategy instructions and time to carry out the instructions successfully. Interestingly, when both of these conditions are met, they perform as well as their younger counterparts; also, the young do as poorly as the elderly in the control 2–2–6 condition, perhaps because all subjects in this condition have insufficient time and thus encode and retrieve similarly.

The main point of this section is that many different patterns linking rehearsal time to subsequent memory performance have been found in various studies. It is extremely difficult to account for this variety by the proposal that rehearsal simply acts to transfer information about items to LTS. Rather, 'rehearsal' consists of many qualitatively different operations that serve to construct qualitatively different representations of the encoded event. Further, overall performance reflects both encoding and retrieval operations.

Experiments on ageing and divided attention

In this section I shall describe some recent experiments from my own laboratory; the experiments were designed to explore changes in encoding and retrieval as a function of the subject's age. One proposal to account for age differences in memory is that the 'processing resources' necessary to energize mental operations decline with age. If this general hypothesis is valid, then young subjects whose processing resources are reduced might be expected to show the same pattern of memory deficits as old people. Division of attention provides such an example, and we have recently shown that young people learning under divided attention conditions (e.g. performing two tasks simultaneously) do behave like older subjects working under conditions of full attention (Rabinowitz *et al.* 1982). For an event to be well remembered, it must be processed meaningfully, in terms of the subject's schematic knowledge (organized past experience), yet also distinctively from the many routine applications of particular schemata. Such deeply processed, elaborate and distinctive encodings require substantial amounts of processing resource to be carried out; conversely, if insufficient resources are available, the processing system must necessarily fall back on effortless routine encoding operations, which will result in encodings that are very similar to many past encodings and are therefore difficult or impossible to reinstate precisely at the time of retrieval.

It is well established that both ageing (Craik 1977) and divided attention during learning (Murdock 1965) are associated with large decrements in free recall. In both of these cases, recency is unimpaired relative to appropriate control groups, suggesting that neither ageing nor divided attention affect entry of the material into STS. It might therefore be argued that these conditions are instances of reduced rates of transfer from STS to LTS. However, I shall argue instead that the primary deficit is one of impaired semantic processing and that the reduction in memory performance reflects this impairment. This is not to say that older people do not process meaning – clearly, that is much too extreme. Rather, I mean that older people (and young people whose attention is divided) do not process meaning so richly and extensively. There is now excellent evidence showing that meaningfulness can be a matter of degree, and that more precise and extensive processing within the semantic domain is associated with higher levels of retention (Johnson-Laird *et al.* 1978; Stein *et al.* 1982; Till & Walsh 1980). The present

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hypothesis is that ageing and divided attention affect the elaboration and precision of semantic processing, essentially because such processing is effortful and requires greater amounts of processing resource than subjects have available. This reduction in 'processing power' results in the older cognitive system's reflecting the environment in a relative passive manner, rather than actively modifying the environment. However, if the task or the instructions or the materials constrain and guide processing in a specific way, the age deficit is often overcome (Cohen 1979; Craik 1977; Perlmutter 1978; Till & Walsh 1980). Thus age deficits in memory have been characterized as inefficiencies of processing, rather than as true losses or breakages of mechanisms or structures (Craik & Byrd 1982; Perlmutter 1978).

The finding of slight or non-existent age differences in one task or situation but large differences in another has often been taken as evidence for two different stores or systems underlying the two tasks. For example, there are very slight age differences in recall from recency positions yet large age differences in recall from earlier list positions (Craik 1977), and this result has been taken as support for distinct STS and LTS mechanisms. Similarly, Tulving (1983) has cited analogous differential results as support for the distinction between episodic and semantic memory, and Cohen & Squire (1980) take the finding that amnesics have poor episodic memory but preserved memory for procedural learning, to indicate a distinction between systems for 'knowing that' and 'knowing how' (see also Tulving *et al.* 1982).

An alternative explanation seems possible, however. Both encoding and retrieval tasks vary in the degree to which they require self-initiated constructive operations. For example, some encoding operations are so well practised, or the stimuli are so compatible with the relevant processing mechanisms, that the encoding is carried out 'automatically', without conscious effort (e.g. perceiving a picture or an expected word in context). Other encoding operations, for example, involving deductions or inference, require much more attention and effort. Retrieval tasks also vary in the degree to which they require self-initiated constructive operations; some, like free recall, involve minimal 'environmental support', the subject must reconstruct the original event with little help from the cues provided. At the other extreme, 'procedural' tasks such as learning to read mirror-image script or solve jigsaw puzzles requires relatively little self-initiated activity. In these latter tasks there is no need to go beyond the information provided by the environment to reconstruct details of the event (as in recall) or details of the original context of occurrence (as in recognition); in procedural tasks the required operations are specified by the task itself. As a further speculation, self-initiated activities – the necessity to construct mental operations beyond those 'driven' by the environment or automatized by much previous practice – may necessarily involve conscious awareness. Moscovitch (1982) has distinguished two modes of remembering – 'conscious recollection' and 'procedural or skill memory' – again citing evidence from amnesic patients who are impaired in the former mode but 'spared' in the latter mode. My point is that tasks may simply vary in the degree that they require the activation of conscious operations, rather than differing in the involvement of two distinct modes or systems. Table 2 lists a number of common laboratory paradigms used in the study of human memory, arranged in an intuitively determined order reflecting the degree to which the retrieval task is either driven by the environment or demands self-initiated activities. A further real-life task that may require even more self-initiated activity than free recall is 'remembering to remember' – that is, remembering to carry out some task at a later time in the absence of cues (J. Harris, personal communication; Schonfield & Stones 1979). Differential results between two groups of subjects (old and young, say) across these

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TABLE 2. DIFFERENT RETRIEVAL TASKS

test	environmental support	self-initiated activity (conscious awareness?)
free recall	increases	↑
cued recall	↓	↑
recognition	↓	↑
relearning	↓	↑
perceptual learning	↓	↑
procedural learning	↓	increases

different tasks may not reflect the operation of different memory systems, but may more simply reflect different degrees of self-initiated constructive operations required by the tasks (see also Hasher & Zacks 1979).

Some specific empirical questions are now posed, with tentative answers provided by the available experimental evidence.

Is ageing accompanied by a deficit in comprehension?

If age differences in memory are secondary to impaired semantic processing, this impairment should be detectable though behavioural tests. One line of evidence that supports the present contention is that older subjects fail to draw inferences from sentences or prose passages, although they are perfectly capable of remembering verbatim statements (Cohen 1979; Till & Walsh 1980). Elderly people are capable of drawing inferences, however, if they are induced to do so by the task (Till & Walsh 1980) or by the use of easier materials (Zacks & Hasher 1982). Can this type of subtle impairment in semantic processing be more directly linked to memory decrements in the elderly? The results of Till & Walsh (1980) suggest that it can; in one experimental condition they induced more extensive semantic processing in the older subjects by requiring them to generate a word reflecting their understanding of each sentence. This procedure raised the level of later recall of the original sentences to the level achieved by young subjects.

Mark Byrd from my laboratory carried out a study of age differences in memory for stories (Byrd 1981). Each story was approximately 250 words in length and was presented in one of three versions: normal, in which the whole story was presented; no theme, in which thematic elements were removed so that it was possible to follow the action of the characters but not fully understand the reasons for their actions; and random, in which the sentences of the original story were presented in a random order so that the meaning was now very difficult to apprehend. After hearing each story, old (mean age 67 years) and young (mean age 22 years) subjects were given unlimited time for spoken free recall. Their recalled versions were analysed into propositional units by using the method developed by Kintsch (1974). This analysis breaks recall down into various levels, with level 1 reflecting the general gist of the story and lower levels reflecting finer detail. Figure 4 shows that the age differences in recall of the normal story were slight, especially at the higher propositional levels; in the no-theme condition age differences were greater, and in the random condition, age differences were large, especially in recall of the central meaningful elements. The implication again is that if the meaning is made obvious to older subjects, they can comprehend the material and recall it well. If the meaning requires a great deal of effort to accomplish, as in the random story, young subjects

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can still do reasonably well but old subjects now do poorly. It is further suggested that it is not simply lack of motivation that lies behind the older subjects' poorer performance, but rather that lack of adequate processing resources leads to impaired comprehension.

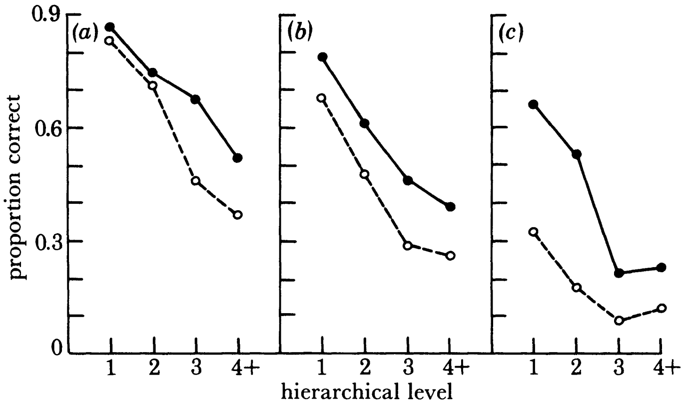

FIGURE 4. Probability of recall of propositions by young (●) and old (○) subjects as a function of experimental condition and heirarchical level. (*a*) Normal story; (*b*) no-theme story; (*c*) random story. (Byrd (1981).)

Contextual integration

An encoded event must be distinctive from other encodings if it is to be well remembered, and one major way in which this distinctiveness may be conferred is by modifying the event's encoded representation in terms of the context in which it occurs. If older people process information less extensively and elaborately, if they are less likely to go 'beyond the information given' than are their younger counterparts, then one reason for poorer episodic memory in older people could be a failure to confer distinctiveness on encoded events by contextual integration. That is, older people may tend to treat the same event on different occasions in 'the same old way', thereby making the wanted event difficult to differentiate from others at retrieval.

Evidence supporting this hypothesis comes from several recent experiments. Simon (1979, expt 2) presented words to be learned in the context of specific sentences; young (22 years) and older (62 years) subjects were asked to study the specific meaning of each word in its sentence context. In a later retention test, the older subjects recalled only slightly more words when the sentence frames were provided as cues (30%) than when no cues were provided (26%), whereas the young subjects improved their recall from 50% with no cues to 77% with sentence-frame cues. Simon's conclusion was that older subjects integrated the word with the sentence less effectively during encoding. Further work (Craik & Simon 1980; Rabinowitz *et al.* 1982) has provided further evidence for poorer contextual integration with age, and has also demonstrated poorer integration in young subjects working under conditions of speeded presentation (Simon 1979) and divided attention (Rabinowitz *et al.* 1982). A failure to integrate items with contextual information may also underlie other memory disorders; for example, Stern (1981) makes this case for amnesic subjects. Both normal and amnesic subjects may encode event and contextual information separately, giving rise to feelings of familiarity, or knowledge of a fact, without knowledge of where or when the event or fact has been encountered previously (see, for example, Huppert & Piercy 1976; Mandler 1980; Schacter & Tulving 1983). Such findings need not be taken as evidence for separate memory systems, however (cf. Schacter & Tulving 1983); an account in terms of different types of information provides a simpler explanation.

Can functional memory deficits be 'repaired'?

If one major determinant of memory performance is the degree of semantic richness of the encoding, and if a failure to achieve this type of encoding during perception and comprehension of the material underlies the poorer performance of older people, it may be asked whether levels of performance would be raised in older subjects if they were induced to carry out the relevant processing operations. A study by White (reported by Craik 1977) showed that whereas there were large age decrements in both recall and recognition after free learning of word lists, this decrement was eliminated by pairing a semantic orienting task at acquisition (deciding whether each word was or was not a member of a specific category) with a recognition task at retrieval. The same pattern of results has also been reported by Perlmutter (1978, 1979), Till & Walsh (1980) and Yokubynas (1979). Much earlier, Hulicka & Grossman (1967) showed that instructions to form meaningful mediators between words benefited old subjects much more than young subjects on a paired-associate learning task. Thus if processing is 'guided' by the task both at encoding and retrieval, the usual age deficits can apparently be reduced or eliminated.

Can other types of memory disorder be reduced in a similar fashion? The answer appears to be that some types can but that some cannot. In the former category, Stein *et al.* (1982) have shown that memory for sentences in academically weak children aged 10–11 years can be dramatically increased (from 40 to 90% recall) by training them to generate precise, relevant semantic elaborations to the presented sentences. In another recent study Hashtroudi *et al.* (1983) showed that verbal memory in alcoholically intoxicated subjects could be greatly improved by requiring their subjects to generate a meaningful continuation to the presented sentence. In my own laboratory we have shown that the memory decrement observed in normal young subjects working under divided attention conditions can also be eliminated by pairing orienting tasks at learning with a recognition test at retrieval (Craik & Byrd 1982). This last result gives further support to the idea that division of attention mimics the effects of normal ageing in some ways at least; the present suggestion is that both conditions reflect a reduction in the processing resources available.

While the deleterious effects on memory of ageing, divided attention and intoxication can be reduced by inducing a fuller and more precise understanding of the events to be remembered, other types of memory disorder appear to be less amenable to this treatment. For example, Cermak (1975) reported no differential improvement in amnesic patients' memory performance with the orienting task technique. It seems that the functional memory disorders found in normal ageing and in conditions of divided attention are discontinuous with the more organically based disorder found in amnesics; typically, such patients show little impairment of comprehension, but profound losses of memory (Baddeley 1978, 1982; Squire *et al.* 1983; Warrington & Weiskrantz 1982). It should also be noted that most of the successful 'semantic enrichment' studies have used verbal materials; the effects are very much smaller with pictures or faces as stimuli (Baddeley 1982). One possible reason for this discrepancy is that pictorial stimuli may already be rather effective in eliciting a full, meaningful encoding; adults are highly practised at extracting significance from perceptual scenes and sequences. Arguably, verbal materials have a greater range of optional encodings associated with them, i.e. a reader or listener may or may not draw inferences and implications, and make associations or images, from the material presented.

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Similarities between retrieval and encoding processes

Just as encoding processes vary in 'depth', elaboration, extensiveness and precision, retrieval processes may vary in similar ways (Craik & Jacoby 1979; Jacoby 1983*b*). Encoding and retrieval processes may be qualitatively similar, or even identical (Kolers 1973) despite the fact that they are carried out with different goals in mind (Jacoby & Craik 1979). If this suggestion is valid, it should be possible to manipulate the effectiveness of retrieval operations by varying the amount of processing resource available. We have recently conducted an experiment on the effects of divided attention on retrieval to explore this possibility.

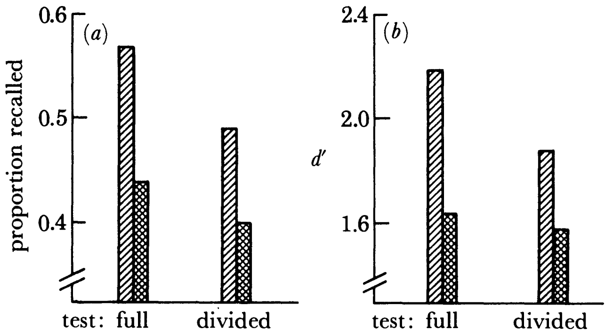

FIGURE 5. Recall (*a*) and recognition (*b*) performance as a function of division of attention at encoding and test. Hatched columns, full attention during encoding; cross-hatched columns, divided attention during encoding.

Subjects were asked to learn lists of 15 unrelated nouns, presented auditorily one word every 2 s, either under conditions of full attention or while they were performing a concurrent task. This secondary task was to sort playing cards into four suits at the rate of $1\frac{1}{2}$ s per card. An auditory signal indicated the end of list presentation and instructed the subject to recall as many words as possible, starting with the last few words. Subjects recalled verbally for 1 min, again under full or divided attention; three lists of words were presented under each of the four conditions combining full or divided attention at encoding and retrieval. After the recall of all 12 lists, subjects were given an auditory recognition test for the words (excluding primacy and recency items); again, half of the words were tested under conditions of full attention and half under divided attention.

Figure 5 confirms that division of attention at encoding had a large effect on both recall and recognition ($P < 0.001$ in both cases). For recall, there is also a significant effect of division of attention at retrieval, $F(1, 15) = 19.52$, $P < 0.001$, with no interaction between the effects of divided attention at encoding and retrieval. For recognition, however, there is no reliable effect of divided attention at retrieval ($F(1, 15) = 2.33$, $P = 0.15$) and a marginally significant interaction between the effects of divided attention at encoding and retrieval, $F(1, 15) = 3.82$, $P < 0.07$. Division of attention does therefore reduce the effectiveness of retrieval operations, but more for recall than for recognition. This differential effect of test is in line with my previous suggestion that recall requires more self-initiated activity; from this point of view, it might be expected that recall would be more disrupted than would recognition by the necessity to perform a concurrent task. Overall, the experiment supports the contention that encoding and retrieval processes are similar.

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Conclusions

Summary of present position

The notion of 'transfer' in memory research implies that information about encoded events is copied or conveyed from one location to another. In this article I have argued that the concept of transfer is unnecessary. Memory is to be understood in terms of the qualitative type of encoding constructed (Craik & Lockhart 1972) and the compatibility between encoding and retrieval operations (Kolers 1973; Tulving & Thomson 1973). The type of code formed will depend in turn on interactions among materials, tasks and subjects (Jenkins 1979), making the analysis of overall performance complex yet understandable in principle. This view of memory (or rather remembering) as an activity akin to perceiving, suggests that we should be studying the processes of encoding and retrieval directly, rather than be looking for hypothetical traces or stores. This was the approach strongly advocated by Bartlett (1932) some 50 years ago.

The empirical evidence cited previously showed that Atkinson & Shiffrin's (1968) suggestion that time in STS is the major determinant of permanent memory cannot be maintained. Qualitatively different types of encoding, in combination with different retrieval tasks, are associated with a variety of different patterns linking rehearsal time to subsequent performance. The present suggestion, that performance depends on the representation constructed and the compatibility of that encoded information with the retrieval task, is particularly well supported by Jacoby's (1983) demonstration that performance across three encoding tasks either rises or falls depending on the retrieval test. The finding of equivalent STS performance across two groups of subjects (or experimental conditions), yet differential LTS performance between the two groups, might be taken as evidence for effective STS registration and a failure to transfer information to LTS (Atkinson & Shiffrin 1968). My suggestion, in contrast, is that the encoded representation formed by the poorer group is adequate to support STS performance but inadequate to mediate performance over the long term.

Adequate LTS codes appear to be those in which the encoded event is related meaningfully to previously acquired schematic knowledge yet is also distinctive in some way from that knowledge. 'Meaningfulness' is not an all-or-none characteristic but is a matter of degree (see, for example, Johnson-Laird *et al.* 1978; Stein *et al.* 1982) with deeper, more elaborate, and more precise encodings being associated with higher levels of retention. This view suggests that poor memory should often be related to impaired comprehension, and there is evidence to this effect in elderly subjects (Cohen 1979; Till & Walsh 1980). Further, evidence was presented to show that if more adequate comprehension is induced in such subjects, memory performance improves (Craik 1977; Perlmutter 1978; Till & Walsh 1980). Memory deficits in older people thus appear to reflect inefficiencies of processing and the present suggestion is that depleted processing resources underlie this inefficiency. Finally, it was suggested that different retrieval tasks require different amounts of self-initiated activity on the subject's part (table 2), and that these task differences may account for differences across subjects, rather than the performance differences being attributable to the involvement of different memory systems.

Final remarks

The present account of remembering as being inherently tied to perceiving and understanding fits the data from studies of ageing quite well. It also fits data from other conditions of memory impairment in which it is plausible to assume that processing resources are depleted: divided attention, for example, and more speculatively fatigue, intoxication and depression. However, most cases of clinical amnesia are not well described by the present account, since these patients show at least adequate comprehension yet extremely poor subsequent recollection (Baddeley 1978, 1982). Two possible lines of explanation are; first, that amnesia is essentially a failure of retrieval processes (Warrington & Weiskrantz 1970), possibly a failure in particular to recreate the initial context (Stern 1981), and second, that some 'consolidation' process is necessary to 'fix' in a permanently accessible fashion the changes in neural circuitry induced by the original event (Squire *et al.* 1983). The evidence supporting consolidation is still incomplete, but there seems to be no reason in principle that a psychological account of remembering in terms of depth and elaboration of processing during initial perception and comprehension could not coexist with a more clearly physiological process of altering the underlying neural mechanisms in some permanent fashion.

A second point bearing on the underlying neurophysiology is that if it is more valid to talk about the processing activities of remembering than about memory as the reactivation of specific traces, the search for the physiological correlate of such traces – the engram – may be a futile enterprise. If remembering is closely akin to perceiving, then it is perhaps no more likely that memory traces exist in the absence of remembering than percepts exist in the absence of perceiving: the activity must be studied while it is occurring. Clearly something in the system must change as a result of experience, but the changes may be diffuse and widespread modifications of the whole cognitive system (Bransford *et al.* 1977) so that the system now interacts with aspects of the environment in a different way, rather than events being recorded specifically and discretely like events on a video recorder. There is now at least some evidence to suggest that memory is mediated by the same neural systems that subserve perception and action (Squire *et al.* 1983).

As a final word on psychological models of memory, it seems very possible that theorists have not taken the dynamic and interactive nature of remembering sufficiently into account. Information-processing models have tended to describe the system 'at rest' or in isolation, as an entity with an existence separate from its activities. When the level of description moves from anatomy to physiology it is necessary to describe function rather than structure; in a parallel fashion, when we move to the level of psychological description it may be necessary to take interactions with the environment into account as inherent aspects of our models, rather than as qualifiers or modifiers of some fixed underlying reality. This view of modelling – that our goal should be to model the interactions among tasks, environmental events and mental representations of prior knowledge – acknowledges contextualism as the appropriate frame for the psychological description of remembering (Jenkins 1974, 1979) and is in line with a systems approach to human cognition (Simon 1969).

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Discussion

D. A. Routh (*Department of Psychology, University of Bristol, U.K.*) Professor Craik's scheme for the *post-hoc* classification of various data sets (figure 2) appears to give rise to grounds for criticism. The problem stems from the fact that sometimes extremely different forms of retention test are being compared, with the result that it is difficult to avoid either 'floor' or 'ceiling' effects. I am not claiming that *mean* performance was ever at floor or ceiling in the data shown, but rather am drawing attention to the possibility that *median* performance may have been. Theoretically, then, does this not mean that it is sufficient to entertain an account possessing merely the capability of generating two main effects?

F. I. M. Craik. The purpose of figure 2 is simply to illustrate the empirical observation that many different functions relating rehearsal time to subsequent memory performance have been found, and that this diversity does not fit the simple notion that permanent memory reflects only rehearsal time and number of items sharing the buffer. I agree that 'two main effects' can describe first the notion that memory performance improves as rehearsal duration increases, and second that qualitatively different types of rehearsal are associated with different levels of retention. The two further ideas captured in figure 2 are first that different types of rehearsal either give rise to differences in memory level (figure 2*b*) or do not (figure 2*c*) depending on the type of retrieval test, and second that particular memory codes may take different times to form, but that once they are formed, further rehearsal has no further beneficial effect. With regard to floor and ceiling effects, this *may* be a problem with the Geiselman & Bjork study (figure 1), but I do not think it is a concern with the data shown in table 1 or figure 3. Figure 3, for example, illustrates figure 2 (*a*) and (*d*); the data points all lie in the middle ranges between 20 and 70 % correct.

D. E. Broadbent, F.R.S. (*Department of Experimental Psychology, University of Oxford, U.K.*) It is quite useful to have a clear statement of an extreme position but I wonder if I could press Professor Craik about the idea of using *only* processes in explanation, rather than a combination of processes and representations? The problem is that the codes available temporarily, soon after the stimulus, have limits and that these limits are reflected in longer-term retention. Thus for example the limited duration of the articulatory loop provides an explanation for the empirical results of Atkinson & Shiffrin, and it is not clear how process alone can do so.

F. I. M. Craik. I am not sure how totally committed I am to a 'pure process' view of memory, but I do believe that it is possible to describe virtually all the phenomena of remembering *at the psychological level* in terms of processes. Both the articulatory loop and the rehearsal buffer clearly have limits, and one way to think of them is as structures with a limited holding capacity. But it is also possible to think of these concepts as activities that have limits in terms of how much can be performed in a given time. A mediocre juggler, for example, can keep only three balls on the go, even though there is no *structural* limitation on his ability; the limitation, rather, has more to do with his degree of skill. When permanent memories are considered, it again seems necessary at first to talk of codes and representations. But if remembering is thought of as an activity like perceiving, it is possible that the initial experience modifies the underlying physiological machinery so that the machinery now interacts with a repeated event in a different way at the time of the recognition test. That is, the 'memory trace' is perhaps not a record of experience in any direct sense, but is rather a changed disposition for the cognitive machinery to act in a different way. Mechanism and structure are necessary concepts at the level of physiology or anatomy, but not necessarily at the level of psychology.

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