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THE LONG AND THE SHORT OF MEMORY[1]

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This article critically evaluates the evidence regarding the number of dynamically different memory traces mediating human retention. Persistence of sensation and adaptational (fatigue) "memories" are ignored. *Most* of the evidence supporting the distinction between short- and long-term memory traces (primary and secondary memory) is shown to be equally consistent with a single-trace hypothesis. However, three phenomena are considered to support the dual-trace theory over the single-trace theory. There appears to be no evidence, at present, to justify splitting long-term memory into components such as intermediate-term memory and long-term memory. A major purpose of the review is to direct attention toward phenomena that are truly relevant for deciding such issues.

One of the most frequently considered theoretical questions in memory research over the last 15 years has been whether it is useful to distinguish between short-term and long-term memory traces (primary and secondary memory). Do human beings have one or two (or more) dynamically different memory traces mediating performance at retention intervals ranging from several seconds to several years? The present article considers this theoretical question. Consideration of this question is limited primarily to verbal memory because that is where the relevant evidence exists. Sensory memories (persistence of vision or audition, adaptation, etc.) are ignored.

Specifically, this article is concerned with the validity of distinguishing between some kind of short-term memory with a time constant on the order of seconds (the "short trace") from some type of longer term memory that may last from tens of seconds to years (the "long trace"). There is no evidence at present to justify splitting long-term memory into components such as intermediate- versus long-term memory. The physiological evidence for this distinction is not at all convincing (see review by Deutsch, 1969), and the psychological evidence presented by Wickelgren (1969) has been better accounted for by a single long trace with increasing resistance to forgetting (Wickelgren, 1972b).

Throughout this article, the terms "short-term and long-term retention" will represent the methodological distinction between memory tested at short delays (usually less than 10 seconds) versus long delays (tens of seconds to years). The terms "short and long traces" will represent an assumed theoretical distinction between two dynamically different memory traces.

The present article is organized into three sections: The first section discusses some general concepts that are important for making distinctions between memory traces. The second section considers a large variety of irrelevant evidence for distinguishing between short and long traces, evidence which is irrelevant either because it can be interpreted within a single-trace theory or because it can be interpreted by assuming dynamically identical traces in two different coding modalities (e.g., phonetic versus semantic modalities). The third section considers relevant dynamic evidence for distinguishing between short and long traces.

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Conceptual Background

Although there are three lines of relatively convincing evidence favoring a distinction between short and long traces (primary and secondary memory), it is a sad fact that the vast majority of all of the cited evidence is worthless for making the distinction between short and long traces. There are various reasons why different pieces of evidence are worthless, but there are two recurrent conceptual errors. First, coding differences are often confused with dynamic differences. Second, differences in decay rate are considered to establish differences in trace dynamics. These conceptual errors are discussed in this section.

If the subject learns two word-word paired associates, say A-B and C-D, one would say that two different memory traces were established: one trace for the A-B association and one trace for the C-D association. If anyone doubted that these were two different memory traces, it could be demonstrated that they were different by showing that C-E_i interpolated learning caused more interference with the C-D association than with the A-B association and vice versa for interpolated A-E_i interpolated learning. The fact that different manipulations affect the two traces differently does not argue that the two traces are dynamically different. That is to say, this evidence does not establish that the laws of forgetting are different for the two memory traces. In fact, in this case, undoubtedly the two traces would be considered to be stored in the same coding modality as well as having the same dynamic laws of forgetting.

Now let us consider a slightly less obvious case where memory for a picture is compared with memory for an abstract (not easily visualizable) word-word paired associate. In this case, one presumes that not only are the two traces logically different, but they are stored in what we might consider to be two different coding modalities (visual versus verbal). It is beyond the scope of this article to consider what observations and manipulations are relevant for demonstrating differences in coding modalities.

However, any such demonstrations of a modality difference, by themselves, prove nothing regarding the question of whether the two traces are dynamically different. Two traces coded in different modalities may have the same dynamic laws of forgetting, as we assume hold for two traces which are simply logically different (A-B versus C-D) but are stored in the same coding modality. To demonstrate that there are two dynamically different types of memory traces, the short trace and the long trace, it is necessary to show that any alleged differences in forgetting for two types of memory traces can only be explained by assuming a dynamic difference, not simply a coding difference.

The second conceptual error very frequently made in this area is that differences in forgetting rate (decay rate) alone are evidence for distinguishing short and long traces. Under many conditions, memory appears to undergo an initial period of rapid forgetting followed by a long period of relatively slower forgetting. From this fact alone, some investigators have concluded in favor of two memory traces: the short trace characterized by rapid forgetting and the long trace characterized by slow forgetting. Fallacies in this line of reasoning have been discussed previously by Gruneberg (1970), and the present discussion is largely a restatement of Gruneberg's arguments.

There are two basic fallacies involved in the superficial use of differences in forgetting rate to distinguish two dynamically different memory traces. First, rapid forgetting occurring immediately after learning does not, in and of itself, require the assumption of two memory traces. Ever since Jost's second law was formulated in the late 1800s (see Hovland, 1951), it has been established by virtually every relevant study that the forgetting rate for long-term retention decreases with increasing delay, no matter what dependent measure of memory is used. A recent quantitative study of this phenomenon by Wickelgren (1972b) also found that forgetting rate is continuously decreasing with increasing retention interval from delays of tens of seconds up to delays of over two years. Thus, from the mere *qualitative* finding of decreasing decay rate with increasing retention interval, one cannot argue for a distinction between short and long memory traces, since the long trace itself very likely demonstrates this qualitative phenomena.

Only if one could show that retention functions which fit at long retention intervals cannot be extrapolated to fit the results for short retention intervals (under 10 seconds) would there be evidence of the existence of a short trace distinct from the long trace. There have been careful quantitative analyses attempting to demonstrate the necessity for assuming two memory traces (e.g., Atkinson & Crothers, 1964; Waugh & Norman, 1965; Wickelgren, 1969). However, none of these quantitative studies assumed a long trace that was rapidly decreasing in its decay rate over the first 10 seconds. Furthermore, there are many options for extrapolation of the long trace into the first 10 seconds that are consistent with the form of the retention function for long delays, and it is quite possible that one of these options would provide a good fit of the single-trace theory to the data at short retention intervals. I know this is true in some cases where I previously thought only a dual-trace theory would fit. At present, it is not clear what conclusions can be drawn regarding the number of traces operating at short retention intervals under conditions where there is some long-term retention.

The second defect in the rapid forgetting argument is that, even if one could show that two memory traces with different decay rates are required in order to fit retention functions across a variety of situations, the two traces might differ in decay rate merely because they came from different coding modalities. The physiological character of the trace and the underlying psychological laws of forgetting in both cases might be identical.

For example, verbal memory traces may include a rapidly decaying phonetic component and a more slowly decaying semantic component. It is known that the forgetting rate for long-term retention (presumably the long trace) is greater the greater the similarity of interpolated to original material (even by a recognition measure—see Wickelgren, 1972b, for a review). Thus, the phonetic trace will have a much higher average similarity between original and interpolated material than will the semantic trace. Both traces might be subject to the same factors producing forgetting in precisely the same way, with the only difference being due to the similarity between original and interpolated material. Thus, even vast differences in decay rate for two traces do not necessarily imply dynamic differences. Precisely this point has been made by Gruneberg (1970).

Irrelevant Evidence

Associative versus Nonassociative Structure of Memory

Two basic types of memory structures have been proposed as models for human memory: associative and nonassociative. In an associative memory, each concept has a relatively unique internal representative and these internal representatives have different degrees of association to each other depending upon how frequently they have been contiguously activated in the past. By contrast, in a nonassociative memory, there is an ordered set of locations (boxes, registers, cells, etc.) into which the internal representative of any concept can be coded, and sequences of concepts are stored in order in this ordered set of locations. A tape recorder is a good example of a nonassociative memory. As each successive sound occurs, a pattern representing that sound is impressed on a successive portion of the magnetic recording tape.

Human long-term verbal memory has long been regarded as being associative, though psychologists have rarely attempted to state a precise definition of associative memory, let alone give systematic consideration to evidence relevant to the issue. Elsewhere, Wickelgren (1972a) has given a relatively precise definition of an associative memory and discussed several lines of evidence for the proposition that long-term verbal memory is associative.

During the revival of interest in short-term memory in the late 1950s and early 1960s, many short-term memory researchers implicitly or explicitly assumed that short-term retention was from a nonassociative memory ("buffer" storage). If this were true and if long-term retention were from an associative memory, then clearly there would be two traces with fundamentally different coding properties. Such a fundamental difference in coding would virtually prohibit the possibility that the two traces could have identical dynamics.

However, there never was any evidence for the nonassociative character of verbal short-term memory, and Wickelgren (1965a, 1965b, 1965c, 1966, 1967b, 1972a) performed a series of studies to demonstrate that short-term memory is also associative. Thus, there is no support here for a dual-trace theory.

Phonetic versus Semantic Coding

At one point, it was conjectured that short-term verbal retention was from a phonetic modality while long-term verbal retention was from a semantic modality. It is now quite clear that verbal short-term retention can include an encoding of both phonetic and semantic features, and that verbal long-term retention can include an encoding of both phonetic and semantic features. The earlier hypothesis was always absurd on the face of it, since understanding spoken speech requires that the meaning of words be available within hundreds of milliseconds following presentation, and speech recognition and articulation require long-term memory for the phonetic constituents of words. Furthermore, considerable formal experimental evidence now exists for the proposition that both phonetic and semantic memories are potentially available at both short and long retention intervals (see Shulman, 1971, for a thorough review; see also Gruneberg, Colwill, Winfrow, & Woods, 1970; Gruneberg & Sykes, 1969; Shulman, 1970, 1972).

When subjects read words rapidly without getting the meaning, only the phonetic trace may be formed. When long retention intervals are filled with interpolated verbal activity, only the semantic trace may be available (the phonetic trace having been completely destroyed or made irretrievable by interference from the interpolated material). However, both phonetic and semantic traces can be present at both short and long retention intervals.

At this point, it is appropriate to raise the question of what this all has to do with the issue under discussion, namely, distinguishing two dynamically different types of traces.

The question of the existence of two coding modalities for verbal material is largely orthogonal to the question of the existence of two dynamically different traces. The independent character of these two theoretical issues is easy to demonstrate. It might be that there is only one dynamic type of memory trace in the phonetic coding modality, and the same type of trace also operates in the semantic modality. Alternatively, there may be only one dynamic type of trace in the phonetic modality, but it may have different dynamic properties from the single memory trace operative in the semantic modality. Still another alternative is that either or both of the phonetic and semantic coding modalities has both short and long traces operative. This could produce a short and long phonetic trace and a short and long semantic trace. At present, there is no evidence to indicate which of these possibilities obtains. Thus, there is no support here for distinguishing two dynamically different memory traces.

Two-Component Retention Functions and the Recency Effect

Both free recall and probe recall paradigms exhibit substantial recency effects: The terminal item in a list is recalled with a probability near unity and correct recall decreases rapidly the farther an item is from the end of the list. In the middle or initial portions of a list, the proportion correct is still above chance but declines at a far slower rate as a function of further increases in the retention interval. For long lists, there appears to be a nearly asymptotic level of recall over the middle of the list with a small primacy effect (to be ignored in the present discussion) and a large recency effect. Recall from the more slowly decaying (or asymptotic) section of the serial position curves is viewed to be based on the long trace (secondary memory) and recall from the recency section to be based either on the short trace (primary memory) alone or on a combination of both short and long traces.

This argument for distinguishing short and long traces is defective on at least two different counts. First, as discussed in the Conceptual Background section, the fact that the memory trace appears to be decaying more rapidly initially after learning and then more slowly does not, in and of itself, require the assumption of two memory traces. Long-term retention, by itself, demonstrates this phenomenon and the strength-resistance theory of Wickelgren (1972b, 1974) accounts for the continuously declining decay rate with a single trace. Second, even if one showed that the retention function which fit at long retention intervals could not be extrapolated to fit at short retention intervals, one still would not have proved the necessity of assuming two dynamically different memory traces. The two traces could be a phonetic and a semantic trace, different in coding properties and in decay rate, but not necessarily in basic dynamic properties.

In the free-recall studies, where the middle positions of the list appear to form an asymptote, it might be argued that one had to assume two traces because one trace decayed and the other did not decay at all. However, one knows from other studies that long traces must be assumed to be decaying, albeit at a rate sufficiently slow to show little difference over retention intervals from 20 to 40 seconds.

In addition, the free-recall paradigm does not control order of recall and rehearsal strategies adequately to permit using the exact shape of the serial position function to infer anything about the number of traces and their dynamic properties. For example, Rundus, Loftus, and Atkinson (1970) have demonstrated that the frequency of rehearsal declines monotonically from the beginning to the end of the list in a free-recall study. Given this fact, it is perfectly reasonable to interpret the "asymptotic" middle section of free-recall serial position curves to be reflecting an approximately even trade-off between degree of learning and length of retention interval. With important uncontrolled factors such as amount of rehearsal and amount of prior output (retrieval) interference, it is rather ridiculous to try to conclude anything about the dynamics of memory from free recall.

Differential Effects on the Serial Position Curve

A principal strategy in attempting to verify the distinction between short and long traces has been to determine whether variables can be found that affect only the terminal section of the serial position curve or only the initial and medial sections. If a variable affects only the terminal section, it is presumed to be affecting only the short trace. If a variable affects only the initial and medial sections or if the variable has a "constant" effect across all serial positions, then the variable is presumed to be affecting only the long trace.

Across the entire gamut of such studies, there appears to be some flexibility with respect to whether the "subtraction method" is applied under the assumption that a variable affecting the long trace will show up uniformly at all serial positions or whether the subtraction method is not applied under the assumption that the long trace only appears in the initial and medial positions. One might object to this flexibility. However, since none of these studies provides any evidence that is definitive in demonstrating the distinction between short and long traces for a variety of other reasons, it is not necessary to quibble about whether or not to apply the subtraction method or what theoretically motivated subtraction method to use.

Interpolated interference. A variety of studies have now demonstrated that requiring subjects to count backwards, pronounce words, or engage in a variety of other interpolated interfering activities following presentation of a list depresses the terminal section of the serial position curve and has a relatively small effect on the nonterminal sections. This effect has been found most frequently in free recall (Bartz & Salehi, 1970; Glanzer & Cunitz, 1966; Glanzer, Gianutsos, & Dubin, 1969; Glanzer & Schwartz, 1971; Postman & Phillips, 1965; Raymond, 1969), but similar effects have also been found in probe recall with paired associates (Rundus, 1970). If it were possible to argue that there was indeed *no* effect of interpolated material on the nonterminal section of the serial position curve, then this evidence might be taken as a definitive demonstration of the existence of two dynamically different memory traces. However, studies typically demonstrate some, albeit smaller, decremental effect of interpolated interference on the initial and medial sections of the serial position curve in conjunction with the greater effect on the terminal section. Furthermore, it is well known from other studies that long-term retention is decreased by retroactive interference, so whether or not the effect is observed in these studies, or is statistically significant, is a matter of no consequence. As Gruneberg (1970) has pointed out, nonterminal items have already gone through their period of steepest decline due to the interference from subsequent list items. So with a single trace theory, one expects to see a much larger effect of the postlist task on terminal than on nonterminal items. Thus, this evidence is worthless for distinguishing between short and long traces.

Order of recall. Studies by Deese (1957), Murdock (1963), Raffel (1936), and Tulving and Arbuckle (1963, 1966) show that forcing subjects to recall the early items of a list first greatly reduces the recall of terminal items but has little effect on nonterminal items. This effect is the output interference analogue of the effects of an interpolated interfering task. Precisely the same arguments apply regarding its lack of definitiveness for the single- versus dual-trace issue.

Long-delayed recall and recognition. Although items in terminal positions are recalled with the highest probability in immediate free recall, Craik (1970) demonstrated that terminal items actually had lower "final" recall (after a sequence of 10 free-recall lists) than did items in either initial or medial positions. These results have been essentially replicated for a three-week delayed recognition test by Rundus et al. (1970), though the delayed recognition of terminal items was not substantially worse than that of medial list items. These results were viewed as somewhat surprising in that terminal items were retrieved with highest probability in immediate recall, but nevertheless had a lower probability of final recall at the end of the entire session. The dual-trace interpretation was that terminal items were recalled well on the basis of the short trace (primary memory) even though they had lower degree of long trace acquisition. Craik interpreted the results "to pose a serious problem for one-process models [p. 148]."

Once again, the conclusion is unwarranted. According to a single trace theory, the terminal items could have a lower degree of acquisition but be recalled better immediately after the end of a list because of their shorter retention interval. By the end of the session, the relative difference in retention intervals for terminal versus nonterminal items is negligible, and the final recall reflects only the initial difference in degree of acquisition (largely due to greater rehearsal of initial items according to Rundus et al., 1970). The single trace explanation of these results is completely straightforward, and this phenomenon gives no support whatsoever for two traces.

Repetition versus imagery instructions. Smith, Barresi, and Gross (1971) demonstrated that instructing subjects to repeatedly pronounce (rehearse) paired associates produced superior probed recall for the terminal pairs of the list, but inferior performance for nonterminal pairs, by comparison to imagery instructions. This result was taken to indicate that imagery improved the long trace (secondary memory) more than repetition, but that repetition benefited the short traces (primary memory) more than imagery. This experiment probably does demonstrate the existence of two memory traces with different coding properties, namely, a visual trace and a verbal phonetic trace, with the visual trace having the slower decay rate under the conditions of this experiment. However, for reasons mentioned in the Conceptual Background section, there is no reason on the basis of this study to conclude that the dynamic properties of these two traces are different. For all we know on the basis of this study, the phonetic trace mediating superior performance for the repetition group at the terminal positions may be a long-term phonetic trace that is rapidly interfered with by presentation of subsequent pairs.

Presentation rate. By contrast to the relatively small number of variables that are alleged to affect only the terminal section of the serial position curve, rate of presentation is but one of many variables alleged to affect primarily initial and medial sections of serial position curves. Glanzer and Cunitz (1966), Murdock (1962), and Raymond (1969) have all found that a slower rate of presentation of items facilitates free recall of items from initial and medial sections of a list while having no effect whatsoever on the recall of terminal items. This, it is alleged, supports the distinction between short and long traces, since the hypothesized two traces appear to be affected differently by the independent variable of presentation rate. The conclusion is completely unwarranted.

In the first place, it must be noted that varying presentation rate in this design confounds two important variables, namely, study time for each item and the retention interval (measured in time). Thus, it is pertinent to ask how each of these two more basic variables is affecting the terminal versus the nonterminal sections of the serial position curve. When study time has been manipulated independently of retention interval, increased study time is known to have a beneficial effect at all retention intervals (Hellyer, 1962; Peterson & Peterson, 1959; Wickelgren, 1969; Wickelgren & Norman, 1971). According to a dual-trace analysis of these studies, increased study time must be presumed to be increasing the level of acquisition of both short and long traces. Thus, it would be absurd to believe that study time is having a qualitatively different effect on the hypothesized two-component traces in the free-recall studies. What is presumably happening in the confounded free-recall studies is that the increased delay for slower presentation rates is approximately compensating for the beneficial effects of increased study time for the terminal items but failing to compensate for the nonterminal items. This could be because there are two memory traces and the beneficial effects of increased study time are substantially greater for the long trace than for the short trace. However, the rate of decay of long traces is known to decrease with increasing delay. Thus, the effects of increased delay for the terminal items ought to be substantially greater than for the nonterminal items, assuming the single-trace theory. The point is that qualitative analyses cannot decide the issue. Only a thorough quantitative analysis that is unavailable at present could perhaps make a case for the dual-trace theory.

In the second place, since these presentation-rate effects are for free recall, there is always the possibility that the results are due to a confounding with rehearsal strategies or order of recall. For example, at slower presentation rates, subjects may report nonterminal items earlier and surely do rehearse nonterminal items more than at faster presentation rates. Such possible and probable confoundings completely vitiate this phenomenon as evidence for two separate memory traces.

Modality effects. The initial Murdock (1966) article showed a superiority at terminal positions for auditory presentation and a crossover demonstrating superiority at initial positions for visual presentation using a probed paired-associate design. However, further studies by Murdock (1967, 1968, 1969) have obtained a variety of results including consistent superiority for auditory presentation at all positions, superiority for auditory presentation at terminal positions turning into no difference at initial positions, and even greater superiority for auditory presentation at initial positions than at terminal positions. Although the overall tendency is for a greater superiority of auditory presentation at terminal positions, the findings are not completely consistent in demonstrating a differential effect of this variable on retention at longer versus shorter retention intervals. However, even if the most extreme effect, namely, a crossover with auditory versus visual presentation, could be consistently obtained, it would not imply two dynamically different memory traces. Just as with the crossover in the Smith et al. (1971) study of imagery versus repetition instructions, the results might be due to the presence of phonetic versus visual traces with essentially equivalent dynamics (though different rates of decay under the experimental conditions). Even for materials assumed to be processed in the same modality, decay rate varies with the similarity of interpolated learning to original learning (Wickelgren, 1972b). Thus, it is not possible to argue that a difference in decay rate, in and of itself, implies a difference in basic trace dynamics, since these different decay rates may simply reflect differences in the similarity of interpolated to original material in different modalities of storage.

Familiarity. Raymond (1969) and Sumby (1963) have shown that free recall of high frequency words is superior to low frequency words for nonterminal items, but only marginally superior for terminal items. Along the same line, Raymond demonstrated a significantly greater free recall of words over trigrams for nonterminal positions, but an insignificant superiority of words over trigrams for terminal positions after the subtraction method had been used. Since the difference appears to be quantitative, not qualitative, an established quantitative theory regarding trace dynamics is required in order to argue for two traces. Furthermore, these studies use free recall for which the results may be confounded by differences in rehearsal strategies and order of report. Finally, even if it could be established that there were two traces involved, the two traces might differ only in their coding properties and not in their dynamic properties. Specifically, familiarity might influence the degree of acquisition in the semantic modality more than in the phonetic modality, but the storage dynamics of both traces could follow the same laws.

List length. In free recall, Murdock (1962) and Postman and Phillips (1965) have found that increased list length decreases the probability of correct recall at nonterminal positions but not at terminal positions. Comparing the effects of list length as a function of serial position is a rather difficult thing to do, since it is not clear what positions should be compared. Because there are both substantial primacy and recency effects in free recall, it is reasonable to equate either starting from the end of the list or starting from the beginning of the list. If one equates positions starting from the end of a list, the recall probabilities for terminal items are not very different for different list lengths, but at some point earlier in the list, the shorter list lengths lie above the longer list lengths in recall probability.

Within a single-trace theory, this effect may simply be attributed to the greater opportunity for rehearsal that earlier items have on the list as compared to later items and need imply nothing whatsoever concerning the presence of two versus one memory trace. Equating from the end means that greater list length implies a greater number of prior items at each position being compared. It is reasonable to assume both a priori and on the evidence of Rundus and Atkinson (1970) that the more prior list items, the fewer later rehearsals an item receives. Thus, it will be remembered less well. However, this effect should be small to nonexistent for terminal items since they have few to no subsequent opportunities for rehearsal prior to recall.

The fact that in longer list lengths (20 items or more) there appears to be an approximately asymptotic section of the serial position curve in the middle of the list, does not make this comparison any more relevant to the issue of one versus two memory traces. All that the approximately asymptotic middle section means is that a combination of rehearsal strategies, initial acquisition differences, order of report, and differential retention interval is approximately balancing for these serial positions. Since list length affects the degree of primacy, rehearsal strategies, and possibly order of report for this asymptotic section on the curve, it would not be surprising if the various variables should balance out at a higher level for shorter list lengths, even if only a single memory trace were present. Interpretation of these free-recall data is so complex that at present absolutely nothing can be concluded from them with respect to the single- versus dual-trace issue.

Concurrent task load. Murdock (1965) and Silverstein and Glanzer (1971) showed that requiring subjects to perform a concurrent task (card sorting and number addition) during presentation of a list lowers recall of the nonterminal items in the list. The more difficult the concurrent task, the greater the effect. This effect is absent or possibly reversed at terminal positions. Once again, the differential effect of this variable on the terminal versus nonterminal sections of the serial position curve is not useful evidence for distinguishing two memory traces. There could well be only a single memory trace with subjects adopting different rehearsal strategies under the different conditions, namely, rehearsing initial and medial items more frequently later in the list when there was no concurrent task or an easy concurrent task than when there was a more difficult concurrent task. Rehearsal strategies of this type could lead precisely to the result obtained. Indeed, Murdock (1965) interpreted his results in essentially this way without appealing to any dual-trace explanation.

There is actually a study by Bartz and Salehi (1970) that favors Murdock's differential rehearsal interpretation over Glanzer's (1971) dual-trace explanation. According to the Glanzer notion that the subsidiary task affects the long trace, but not the short trace, one should expect to see an effect of the difficulty of the concurrent task on the strength of the long trace at all serial positions of the list. However, according to the differential rehearsal interpretation, one should expect to see it primarily in the initial and medial positions but not the terminal positions of the list. By using an interpolated interference task (backward counting) to eliminate any possible short-term component, Bartz and Salehi were able to show that the effect of the difficulty of the concurrent sorting task was present only at the initial and medial serial positions and not at the terminal serial positions. Thus, the differential rehearsal explanation appears to provide a more satisfactory explanation of these results than the dual-trace explanation.

Associative structure. Glanzer and Schwartz (1971) have demonstrated that the free recall of highly associated word pairs is greater than that of unassociated word pairs at all positions of the list, with a subtraction method being used to determine that the effect was entirely on the hypothesized long trace and not at all on the short trace. A postlist interference task was used to estimate the long trace component without contamination by short trace components. The validity of this evidence depends completely on the validity of the particular subtraction method chosen. In the absence of any knowledge regarding exactly how short traces and long traces combine to produce a decision and interact in other ways, it is difficult to derive great confidence from the result of any particular subtraction analysis. In addition, of course, even if there are two traces operative in the situation, they may well differ only in coding properties and not dynamic properties as discussed previously. Namely, the two traces may be phonetic and semantic traces that differ in decay rates because of different degrees of similarity of the encoding in each modality to the retroactively interfering material. Given that the traces differ in coding properties in this manner, one expects that associative structure would affect primarily or exclusively the degree of acquisition of the semantic trace, not the phonetic trace.

Spacing of Repetitions

Bjork (1970) has surveyed the findings with regard to the efficacy of multiple learning trials as a function of the spacing between repetitions and come to the following conclusions: (*a*) Massed repetitions are superior to spaced repetitions when performance is measured after very short retention intervals (seconds) and (*b*) spaced repetitions are superior to massed repetitions at longer retention intervals, with the improvement increasing up to an optimum degree of spacing and then declining thereafter. Wickelgren (1970a) gave a dual-trace explanation of these findings: Short retention intervals rely primarily on the short trace and massed repetitions give less time for forgetting in short-term memory. Spaced repetitions improve long-term memory because a period of 10 to 30 seconds is required for consolidation of the long trace for the previous presentation. This explanation is probably wrong even if the dual-trace theory is correct.

In any event, the qualitative results can equally well be given a single-trace explanation. The explanation is as follows: Massed repetitions give higher initial degrees of learning after the last repetition, since little time elapses for decay of the traces from earlier presentations. However, since the decay rate for memory traces decreases with increasing delay (Wickelgren, 1972b), the decay rate of the trace for items after spaced repetitions will be lower than after massed repetitions. Thus, one should obtain a crossover, with lower initial degree of learning for spaced repetitions leading to poorer performance at short retention intervals, but lower decay rate after spaced repetitions leading to better performance at longer retention intervals. Thus, these phenomena are utterly inconclusive with regard to distinguishing between single- and dual-trace theories.

Selective Impairment of Auditory Verbal Short-Term Memory

Shallice and Warrington (1970) and Warrington and Shallice (1969, 1972) have recently discovered a patient who has extremely poor performance on all verbal short-term memory tasks using auditory presentation, but whose capacity to learn and remember at both short and long retention intervals is relatively normal with visual presentation. At first, there was some suspicion that the patient had a deficit in short-term memory but no deficit in long-term memory, but now it seems that the early results were merely a consequence of a confounding between the supposedly "long-term" tasks and visual presentation of the material. The deficit appears to be a memory modality deficit without necessarily indicating any reason to distinguish short or long traces within a modality or to conclude that the dynamic character of long traces are different in different modalities.

Relevant Dynamic Evidence

Form of the Retention Function

For the reasons mentioned repeatedly earlier in the article, differences in decay rate are not presently sufficient to establish a dynamic distinction between short and long traces. However, if it could be shown that the basic laws of retention for one class of traces that had rapid decay were different from the laws for another class of traces that had slower decay, then there would be sufficient justification for making a dynamic distinction. One of the most basic laws of retention is the mathematical form of the retention function which describes how some measure of the strength of the memory trace changes as a function of retention interval.

In determining the form of the retention function for the long trace, without contamination by the short trace, it is reasonable simply to use long enough retention intervals filled with interfering activity such that the short traces are presumed to be entirely dissipated. Using this method, Wickelgren (1972b) studied long-term retention for a variety of verbal materials using both the continuous and study–test designs, under a variety of different conditions, spanning retention intervals from a minute to over two years. These experiments demonstrated that the long trace cannot be characterized by an exponential decay of strength, but rather required the assumption that susceptibility to decay is continually decreasing. This continual decrease in the susceptibility to decay is handled by assuming that long traces must be characterized by two properties, strength and resistance, with strength decreasing and resistance increasing with delay since learning. The same basic form of retention fits the results of all these studies and may be called an exponential-power decay function: $\ell = \lambda e^{-\psi t^{1-\gamma}}$, where ℓ is the strength of the long trace, λ is the degree of initial acquisition of the long trace, ψ is the rate of decay of the long trace, γ is the exponent of growth of trace resistance, and t is the length of the retention interval.

To study the short trace independently of the long trace is somewhat more difficult, since it presently appears possible, even likely, that the long trace is present at the shortest measurable retention intervals following learning. In any event, it cannot be assumed that the long trace is absent at short delays when it appears to be present at longer delays.

However, there are conditions under which there appears to be no retention at intervals longer than 10 or 20 seconds following learning. Within a dual-trace theory, it is plausible to assume that the retention function in such cases represents only the short trace.

Furthermore, the situations in which no long-term retention appears to be present are precisely those in which a long trace should not be present according to a dual-trace theory. All of the studies that appear to contain no long trace are those for which list items on each trial are selected from a small population with rather little time elapsing between the occurrences of the same item from one trial to the next. Under these circumstances, the long traces for correct and incorrect items on a given trial should be approximately equal. Thus, a measurement of the *difference* in strength between correct and incorrect items on a given trial should reflect only the short component. Probe recognition designs using either digits (Wickelgren & Norman, 1966, 1971) or long lists of letters (Wickelgren, 1970b) fit these requirements for studying only the short trace in isolation from the long trace, and it is precisely these studies that appear to produce no long trace component.

When the form of the retention function for the short trace is analyzed in these studies, the results contrast sharply with those observed for the long trace. Wickelgren and Norman (1966, 1971) and Wickelgren (1970b) found that the short trace followed an exponential decay: $s = \alpha e^{-\beta t}$, where s is the strength of the short trace, α is the initial level of acquisition of the short trace, β is the decay rate, and t is the retention interval. Empirical retention functions in these studies cannot be well fit by the exponential-power function that fits long-term retention.

Similarity and Storage Interference

Wickelgren (1972b) has summarized the results of more than a dozen studies that all agree in demonstrating that storage interference (unlearning) for the long trace (as measured by recognition tests at long-retention intervals), is greater, the greater the similarity of interpolated material to original material. Only one study (Bower & Bostrum, 1968) failed to find a difference on a long-term recognition test between the AB–AC paradigm and the AB–CD paradigm. Also, in the most highly publicized such study, namely, Postman and Stark (1969), the difference between AB–AC and AB–CD was not significant, though the difference between AB–ABr and AB–CD was statistically significant. However, in the Postman and Stark study, the difference between AB–AC and AB–CD paradigms was quite large, though too near the 100% correct ceiling to be statistically significant. In all of the other dozen or more studies, the difference between AB–AC and AB–CD paradigms was statistically significant. Thus, there can be no doubt that increasing the similarity of interfering material increases storage interference (unlearning) measured at long-retention intervals.

By contrast, Wickelgren (1967a) demonstrated that in retention measured under the previously mentioned conditions that produce a simple exponentially decaying trace (interpreted to be the short trace), an AB–AC design produces no greater interference than an AB–CD design. This probably does not mean that short-term memory is a passive decay process. Deutsch (1970) showed that learning interpolated material within the same modality produces a greater storage interference effect on the short-term trace than does learning interpolated material in a different modality. Also, the relation between decay rate and presentation rate appears to require the assumption of a type of storage interference effect for the short trace (Wickelgren, 1970b, 1974). However, storage interference for the short trace appears to be independent of a "fine-grain" similarity of the interpolated material to the original material within the same modality.

Wickelgren (1967a) used a serial list design with auditory presentation, and the finding have also been replicated using a paired-associate design with visual presentation. However, this finding for short-term memory really needs to be demonstrated more extensively and by other investigators before the finding can be taken as evidence for the distinctively different character of storage interference for short and long traces. If replicable, this finding stands as good evidence for distinguishing two traces in the absence of any single trace explanation of such a fundamental difference in storage interference.

Long Acquisition Amnesia

The only frequently cited evidence for the distinction between short and long traces which can be regarded as relevant evidence for this distinction comes from the patients who exhibit relatively normal verbal short-term memory coupled with an almost complete inability to form new verbal long-term memory traces (Drachman & Arbit, 1966; Milner, 1966; Scoville & Milner, 1957). I call this phenomenon "long acquisition amnesia." These subjects do show a considerable capacity for perceptual motor learning (Corkin, 1968) and a kind of perceptual learning (Milner, Corkin, & Teuber, 1968; Warrington & Weiskrantz, 1968, 1970). But this does not alter the significance of the finding that short-term retention for verbal material is relatively unimpaired, while the ability to form new long traces for the same type of material is grossly impaired.

At a minimum, the phenomenon of long acquisition amnesia would appear to provide evidence either for two memory traces or for two independent mechanisms (initial learning versus subsequent learning) in the establishment of a single memory trace. The dual-trace explanation appears to be the simpler of the two, and this evidence should, at present, be considered to support the distinction between short and long memory traces.

Conclusion

Although a staggering number of different phenomena have been cited in support of the distinction between short and long traces (primary and secondary memory), the vast majority of these phenomena provide no evidence whatsoever for distinguishing two dynamically different memory traces. Nevertheless, there are three phenomena that do appear to support a dynamic distinction between short and long traces. First, the form of the retention function appears to be quite different for the two traces. Second, fine-grain similarity affects storage interference for the long trace, but not for the short trace (which is only affected by a grosser modality similarity). Third, the long acquisition amnesia phenomena demonstrated by bilateral mesial temporal patients and Korsakoff syndrome patients is somewhat simpler to interpret within a two-trace theory than a single-trace theory.

Although it is reasonable to adopt the two-trace theory as a working hypothesis at present, it is quite important for these phenomena to be investigated further both experimentally and theoretically. In some instances, the results are insufficiently replicated for such an important conclusion, but equally important, it is necessary for many people to think about the significance of these phenomena in order to be sure that alternative single-trace explanations cannot be given for them. One point of this article is to urge that further work concerned with the distinction between short and long traces be devoted to areas that have the potential for being truly relevant to this question, instead of concentrating on irrelevant phenomena.

Finally, there appears to be no reason at present to assume more than one dynamic type of long trace. However, much more research is necessary to determine whether the laws of forgetting assessed at retention intervals of minutes are the same as the laws of forgetting assessed at hours, days, and weeks. Although the dual-trace theory has a limited degree of support at present, considerably more experimental and theoretical work concerned with the exact dynamics of each memory trace will be required before this theory can be considered to have extensive support.

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