2 Age and Memory: Strategies for Localizing the Loss

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Encoding, storage, or retrieval—at which stage is the age decrement in memory localized? The evidence on this issue is becoming more confusing with each additional increment in information. Rather than detailing all of the relevant arguments, only the major positive evidence is summarized here to illustrate the complexity of the problem. In favor of an encoding deficit is the evidence that older adults utilize imagery less often and effectively than younger adults (e.g., Hulicka, 1967; Hulicka & Grossman, 1967; Rowe & Schnore, 1971; Treat & Reese, 1976) and that they exhibit less organization of to-be-remembered items than younger subjects (e.g., Craik, 1968a; Craik & Masani, 1967; Denney, 1974; Hultsch, 1969, 1974). The reports that age differences in retention are eliminated when the age groups are equated for initial learning (e.g., Gladis & Braun, 1958; Hulicka, 1967; Hulicka & Weiss, 1965; Moenster, 1972; Wimer & Wigdor, 1958) can also be interpreted as supporting an encoding deficit. Evidence for a storage deficit is reported by Gordon and Clark (1974) in the finding that older adults exhibit less retention of single items across successive learning trials than do younger adults. Retrieval problems have also been implicated in the reports that age differences are reduced where retrieval requirements are minimized, such as recognition tests (e.g., Craik, 1971; Schonfield & Robertson, 1966) or cued-recall tests (e.g., Hultsch, 1975; Laurence, 1967; Smith, 1977).

The confusion with respect to localizing the age deficit to one stage concerned with encoding, storage, or retrieval led Craik (1977) to conclude: "There is no point in prolonging the debate on whether age differences are due to acquisition or retrieval. Undoubtedly some situation can be found in which acquisition is the major problem . . . while in others, retrieval will be the major

source of difficulty [p. 408]." Such pessimism about the possibility of localizing the age deficit to one critical stage in memory is, in my opinion, fully warranted. The available evidence concerning age differences in specific hypothetical stages or processes in memory is so heterogeneous and contradictory that one can have little confidence that a solution will be soon forthcoming to the problem of identifying the stage or stages responsible for the age impairment in memory.

Part of the difficulty may be that much of the past research concerned with age differences in memory has relied exclusively on one strategy that may not be the most appropriate for localizing age losses in memory. The major focus of the present paper is to consider alternative strategies for specifying the nature of the impairment in memory with increased age. In the process of discussing alternative research strategies, a promising and powerful new interpretation of age differences in memory will be presented.

For the current purposes, a research strategy will be defined as the procedure by which an investigator typically obtains his research hypotheses. If an investigator derives all of his hypotheses from a single source such as a particular type of theory or a specific set of data, he may be considered to be employing a single research strategy. Since the combined fields of memory and aging yield two potential types of theory and two distinct sets of data, four possible strategies for investigating age differences in memory are to derive hypotheses from: (1) memory theory; (2) memory data; (3) aging theory; and (4) aging data.

GENERATING RESEARCH HYPOTHESES FROM MEMORY THEORY

The first strategy, that of deriving hypotheses from existing theories or models of memory, has dominated most of the previous research on age and memory. The prevalence in the aging literature of such terms as interference, short-term memory, long-term memory, stages of encoding, storage, and retrieval, and more recently levels of processing, is one indication of the influence of normative theories in aging research. Indeed, all of these conceptualizations of memory have served to provide an "explanation" for the age deficit in memory, as over the past 20 years this phenomenon has been attributed to an age-related: (1) increase in interference (e.g., Welford, 1958); (2) reduction in long-term or secondary memory but not in short-term or primary memory (e.g., Craik, 1968 a, b); (3) impairment in retrieval but not encoding or storage (e.g., Schonfield & Robertson, 1966); and (4) decrease in depth of processing (e.g., Craik, 1977).

Much of the research inspired by mainstream memory theories has been of high quality, and thus the overall impact of the strategy has been positive. A

problem exists, however, in that researchers seldom consider other strategies for investigating age differences in memory. This is particularly unfortunate when one realizes that it is only an assumption that the hypothetical mechanisms that serve to describe the performance of young adults will also serve to distinguish young adults from older adults. That is, merely because a model or theory has been found to provide an adequate description of the behavior of one population of subjects does not mean that the model or theory will be capable of identifying the dimensions along which two populations of subjects differ in that behavior. In fact, the inconsistency in the literature on age differences in encoding, storage, and retrieval may be interpreted as signifying that the encoding–storage–retrieval trichotomy is inappropriate for characterizing age differences in memory.

It is important to point out that I am not arguing that researchers abandon the strategy of borrowing concepts from current theories of memory to investigate age differences. I am merely advocating that alternative strategies should also be pursued. Obviously, because nearly every theorist seems to introduce one or more new concepts in his theoretical descriptions of memory, no one would seriously maintain that the researcher concerned with age and memory be exhaustive in investigating age differences in every possible theoretical mechanism. I am only suggesting that the researcher also not be exclusive in limiting his investigations to those derived from a particular strategy.

GENERATING RESEARCH HYPOTHESES FROM MEMORY DATA

One alternative strategy for attempting to isolate the locus of age differences in memory is to let the hypotheses for the age deficit emerge from the data base relevant to a particular memory phenomenon. The first step in this approach is to select a well investigated memory paradigm that has several possible effects, i.e., patterns of results, that could be observed. The second step is to compile a list of factors producing each type of effect. A third step is to locate (or conduct) an aging study to determine which of the possible effects is produced by the factor of adult age. The fourth and final step involves examining all factors producing the same effects as the age factor in an attempt to discover a common mechanism. If a mechanism common to all factors producing the same type of performance difference as the age factor can be identified, one might then hypothesize that that mechanism is also responsible for the age differences in memory.

An obvious objection to this strategy is that similarity of effects does not necessarily imply similarity of mechanism. That is, merely because two factors produce the same pattern of results does not mean that the two factors

operate in the same manner. This objection is quite valid; however, the strategy can be effective when used primarily as a source of hypotheses rather than the sole basis for a conclusion.

As an example of this strategy, consider the phenomenon of free-recall memory analyzed in terms of the serial position of the to-be-remembered items at input. The serial position function in free-recall memory has been extensively investigated and thus it possesses a very large data base. Moreover, at least three possible effects of a factor may be determined, as researchers have identified three distinct segments of the function that are differentially influenced by a variety of manipulations.

A highly schematic illustration of the three segments of the serial position function is presented in Fig. 2.1. The solid line in each panel represents the typical pattern obtained in free-recall experiments, and the dotted line indicates the pattern produced by the manipulation of specific factors. There are substantial differences in effect magnitude across different factors, and therefore the patterns portrayed in Fig. 2.1 should be interpreted only qualitatively and not quantitatively.
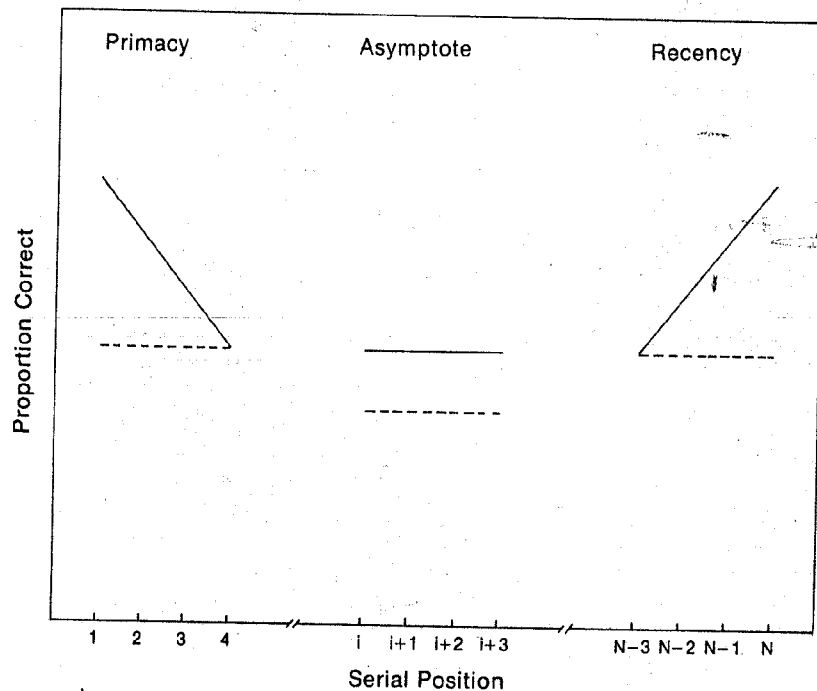

FIG. 2.1. Schematic illustration of serial position effects.

The major factor that has been demonstrated to influence the primacy segment of the serial position function is rehearsal strategy. If subjects are instructed to rehearse an item only when it is being presented (e.g., Brodie & Prytulak, 1975; Fischler, Rundus, & Atkinson, 1970; Glanzer & Meinzer, 1967; Gorfein, 1970; Welch & Burnett, 1924), or if the task is disguised in an incidental learning design such that rehearsal is minimized (e.g., Marshall & Werder, 1972), the primacy segment is much reduced or eliminated.

A large number of factors have been found to influence the asymptote segment of the function relating item recall probability to item position at input. Among these factors are: presentation rate, such that faster rates decrease asymptote (e.g., Bernbach, 1975; Brodie, 1975; Brodie & Murdock, 1977; Brodie & Prytulak, 1975; Craik & Levy, 1970; Gianutsos, 1972; Glanzer & Cunitz, 1966; Glanzer & Razel, 1974; Leicht, 1968; Murdock, 1962; Raymond, 1969); list length, such that longer lists decrease asymptote (e.g., Deese & Kaufman, 1957; Lewis-Smith, 1975; Murdock, 1962; Postman & Phillips, 1965); interpolated activity between items, such that greater activity decreases asymptote (e.g., Baddeley & Hitch, 1974; Baddeley, Scott, Drynan, & Smith, 1969; Bartz & Salehi, 1970; Glanzer & Meinzer, 1967; Gorfein, 1970; Marshall & Werder, 1972; Murdock, 1965; Richardson & Baddeley, 1975; Silverstein & Glanzer, 1971); depth of encoding, such that deeper encoding increases asymptote (e.g., Glanzer & Koppenaal, 1977; Seamon & Murray, 1976); and item pronounceability, such that less pronounceable items have lower asymptote (e.g., Meunier, Stanners, & Meunier, 1971). A variety of factors that might be termed organizational have also been discovered to influence the asymptote segment. For example, the asymptote is higher with: greater item meaningfulness (e.g., Deese & Kaufman, 1957; Glanzer & Razel, 1974; Raymond, 1969); greater semantic relatedness (e.g., Bruce & Crowley, 1970; Craik & Levy, 1970; Glanzer, 1976; Glanzer, Koppenaal, & Nelson, 1972; Glanzer & Schwartz, 1971); greater acoustic similarity (e.g., Bruce & Crowley, 1970; Craik & Levy, 1970; Glanzer, Koppenaal, & Nelson, 1972; Watkins, Watkins, & Crowder, 1974); and greater word frequency (e.g., Raymond, 1969; Sumby, 1963).

Factors identified as influencing the recency segment of the serial position function include: presentation modality, yielding greater recency with auditory than with visual presentation (e.g., Craik, 1969; Murdock & Walker, 1969; Richardson & Baddeley, 1975; Watkins, 1972); post-list activity, yielding smaller recency with greater activity (e.g., Bartz & Salehi, 1970; Brodie, 1975; Brodie & Prytulak, 1975; Glanzer & Cunitz, 1966; Glanzer, Gianutsos, & Dubin, 1969; Glanzer & Schwartz, 1971; Postman & Phillips, 1965; Raymond, 1969; Shuell & Keppel, 1968); and order of output, yielding less recency when the last input items are recalled last (e.g., Craik, 1969).

The next step in this approach to generating hypotheses is to determine the effects of adult age upon the three segments of the serial position function. A

search of the literature on memory and age revealed three studies that conducted serial position analyses, but none is entirely suitable for the present purposes. One (Raymond, 1971) did not include an appropriate young adult control group against which the performance of the older adults could be compared, and another (Craik, 1968b) did not present the serial position functions, but merely reported several theoretical measures derived from the functions. A third study (Arenberg, 1976) did present complete serial position functions but only conducted statistical analyses on the data from the primacy and recency segments of the function. A reasonable conclusion on the basis of these studies, particularly Arenberg's (1976) study, is that the asymptote segment of the function is reduced in older adults compared to younger adults, but that primacy and recency effects, at least judged in relation to the asymptote, are essentially equivalent across age groups. This indicates that, according to the steps outlined above, future efforts should be directed at discovering a mechanism responsible for asymptote effects in serial position functions.

Identifying a mechanism common to all the factors that produce a shift in the asymptote segment of the serial position function is a difficult problem in view of the variety of factors involved. Indeed, it is quite likely that no single mechanism is responsible for all asymptote effects. Nevertheless, we can proceed optimistically in the hope that one or two major mechanisms can be identified and investigated.

One likely candidate for a mechanism responsible for producing at least some of the asymptote effects is the time available for rehearsal of each item. Obviously, increasing the item presentation rate directly reduces the available rehearsal time, but many of the other factors may have similar indirect effects. For example, if earlier list items are rehearsed in alternation with current items, increases in list length will lead to decreases in rehearsal time per item because more earlier items are present in longer lists. Further, activity interpolated between the presentation of items will necessarily reduce the amount of time that can be devoted to rehearsing each item if the activity itself requires time. The various organizational factors might also operate by facilitating rehearsal time for single items or groups of items. Meunier, Stanners, and Meunier (1971) even interpreted their findings with item pronounceability in a similar fashion: "The easier an item is to pronounce, the faster it can be pronounced and the more material can be rehearsed per unit time [p. 123]."

Additional support for the importance of rehearsal time as a mechanism contributing to memory performance is provided by several recent studies utilizing overt rehearsal procedures. Rundus (1971) found a striking positive relationship between number of rehearsals per item and item recall

probability, and he even demonstrated that the number-of-rehearsals–recall-probability relationship held across manipulations of item distinctiveness and interval between repetitions of the same item. Brodie and Prytulak (1975) recently postulated that rehearsal time along with retention interval can account for much of the data on free recall, and they provided impressive evidence in support of this hypothesis. Briefly, their results, which were largely replicated by Brodie and Murdock (1977), indicated that the primacy effect is caused by more rehearsal time allotted to early list items, and that the recency effect is caused by shorter retention intervals of late list items. In addition, both series of studies demonstrated that slower presentation rates led to greater rehearsal time per item than did faster presentation rates, and that the asymptote segment in particular was higher with slower presentation rates.

If amount of time for rehearsal is the mechanism common to most or all factors that lead to changes in the asymptote segment of the serial position function, then we can hypothesize that rehearsal time is also the mechanism responsible for the observed age differences in memory. That is, older adults may have less efficient rehearsal processes than younger adults because they require more time for each rehearsal, and thus can complete fewer rehearsals in a given period of time than can the younger individuals. An experiment providing a test of this hypothesis is described later in this paper.

As far as could be determined, the possibility that there are age differences in rehearsal efficiency would not have been generated from current theories of memory. In this respect, therefore, the strategy of attempting to speculate about the nature of age-related memory loss by beginning from the empirical data rather than existing theories of memory appears to be successful in that it generates novel hypotheses about the locus of the age difficulty in memory.

GENERATING RESEARCH HYPOTHESES FROM AGING THEORY

The third possible strategy listed earlier, that of generating hypotheses about the cause of age differences in memory from theories of aging, may be impractical at the current time. There presently do not appear to be any well established behavioral theories of aging, and thus it is premature to attempt to borrow any ideas or concepts from such theories. When these theories are developed, however, the approach would be similar to the memory theory approach except that the concepts from the aging theory rather than the memory theory would be used to formulate hypotheses about the age differences in memory.

GENERATING RESEARCH HYPOTHESES
FROM AGING DATA

The fourth strategy for deriving hypotheses about the locus of age differences in memory is to examine the data base in aging in order to determine whether known age differences in nonmemory functions could also account for the age differences in memory. Only two steps are involved in this approach. The first is simply to select some phenomenon that has been documented to have a substantial age effect. The second is to attempt to use that age-related phenomenon, or its underlying mechanisms, to speculate about causes for age differences in certain memory functions. If the speculation is plausible, specific testable hypotheses concerned with age differences in memory processes should be deducible.

In order to illustrate this strategy, the general slowing of behavior with increased age is utilized here as the aging phenomenon that might serve as a source of hypotheses concerning age differences in memory. Nearly every textbook in the psychology of aging cites loss of speed as one of the principal manifestations of increased age (e.g., Birren, 1964; Botwinick, 1973; Bromley, 1974; Elias, Elias, & Elias, 1977), and recent reviews cite dozens of studies demonstrating this phenomenon (e.g., Hicks & Birren, 1970; Welford, 1977).

Although a variety of explanations have been proposed (see Botwinick, 1959; Welford & Birren, 1965), there is still much controversy about the reason for the age change in speed. One of the most interesting hypotheses at the present time is what I call the Birren Hypothesis. Birren (e.g., 1956, 1964, 1970, 1974) has repeatedly suggested that the loss of speed associated with increased age is not merely a performance factor that is irrelevant to cognitive abilities, but rather is a reflection of a fundamental change in nervous-system activity. He argues that the slowing affects every event in the nervous system and not just peripheral processes concerned with sensory input or motor output. This has not been a popular argument, as both Birren (1956, 1964, 1974) and Welford (1959) have noted that many psychologists are reluctant to admit that brain mechanisms are involved in age losses in speed because of the implication that the central nervous system deteriorates with increased age. (A related objection, expressed by one of the participants at the conference where this paper was first presented, is that this type of explanation is "theoretically uninteresting" because it offers little opportunity for remedial intervention.) The currently available evidence, however, strongly suggests that nonperipheral factors are involved in the age-related speed loss, and thus the inference that the central nervous sysem is less efficient with increased age seems inevitable.

The Birren Hypothesis of the slowing phenomenon leads to an interesting implication concerning age differences in memory functioning. If all neural events are slowed with age, then one would expect that all time-dependent

processes involved in memory functioning would also exhibit age differences. That is, all memory mechanisms that are sensitive to temporal parameters should lead to poorer performance in older adults because of the underlying speed loss that is associated with increased age. This hypothesis is quite different from the more limited view considered by some earlier investigators, in that it maintains that all processes are slowed with age, not merely those concerned with stimulus registration or response production. In other words, age differences would be expected from this hypothesis even when a self-paced task with unlimited response time was employed as long as some internal process is involved that is dependent upon speed. The critical difference between this hypothesis and other speed hypotheses is that it considers age-related speed loss to be an explanatory, rather than a to-be-explained, phenomenon.

Although not absolutely necessary at the current time, eventually the central-nervous-system speed loss must itself be explained. One possibility is that an increase in neural noise might be responsible. The neural noise concept was first introduced by Crossman and Szafran (1956) and later elaborated by Gregory (1957) and Welford (1958). The essential idea is that the loss of functional brain cells associated with increased age either lowers the strength of neural signals, or increases the level of random background activity, such that the internal signal-to-noise ratio is much reduced with increased age. In order to compensate for this lowered signal-to-noise ratio, it is postulated that the older nervous system integrates neural information over a longer period of time than the younger nervous system. Although still quite speculative, the neural noise concept does provide one conceivable mechanism by which a general central-nervous system slowing, such as that proposed by Birren, could occur.

The well established sensitivity of older adults to the rate of presentation on tests of verbal materials (e.g., Arenberg, 1965, 1967; Canestrari, 1963, 1968; Eisdorfer, Axelrod, & Wilkie, 1963; Kinsbourne & Berryhill, 1972) is consistent with this central speed loss interpretation. In addition, age differences in organization (e.g., Denney, 1974; Hultsch, 1969, 1974) and depth of encoding (e.g., Eysenck, 1974) could be explained with the speed-loss mechanism if it is assumed that the processes of organization and deep encoding require time which is less available in older adults. The existence of age differences in backward memory span, dichotic listening, and divided attention tasks (see Craik, 1977) might also be attributable to a slower attention switching time in older adults. Even interactions between age and type of memory test (e.g., Craik, 1971; Hultsch, 1975; Laurence, 1967; Schonfield & Robertson, 1966; Smith, 1977) might be explained by assuming that recognition and cued-recall tests do not require as strong a memory trace as recall tests and hence are more within the capability of older adults who generally have weaker memory traces because of slower rehearsal processes.

Finally, several experiments (e.g., Anders, Fozard, & Lillyquist, 1972; Anders & Fozard, 1973; Eriksen, Hamlin, & Daye, 1973) employing the Sternberg memory-scanning procedure have provided direct evidence that older adults are slower at searching through memory than younger adults.

The great generality of the speed explanation suggests that it might also encompass phenomena previously attributed to a reduction in "capacity" with increased age (e.g., Welford, 1959). Indeed, it is my contention that rate and speed measures are the best indices of processing capacity presently available. Therefore, until better indices can be developed, this speed interpretation can be considered to be functionally equivalent to interpretations suggesting that some vaguely defined "processing capacity" is reduced with increased age.

It is important to note that the present speed explanation is proposed to account for age differences in memory, and not memory per se. The current speculations therefore do not deny the relevance of mainstream memory models for characterizing the performance of older adults; they merely suggest that the *difference* between young and old adults is best described in terms of a slowing of all time-dependent processes.

AN EXPERIMENTAL TEST OF
SPEED INFLUENCES ON MEMORY

The applicability of the Birren Hypothesis to memory performance was investigated in an experiment I recently conducted with Ruth Wright. Following the arguments presented earlier in this paper, we postulated that the memory process that would most likely be affected by age-related speed loss was rate of rehearsal. A speculative model indicating the manner in which rate of rehearsal might affect memory performance is illustrated in Fig. 2.2. Assumptions implicit in the processes portrayed in Fig. 2.2. are:

1. That rehearsal of items is continuous with both fast and slow rehearsal;
2. That item strength increases a fixed amount with each rehearsal and decays at a constant rate between rehearsals regardless of rehearsal speed; and
3. That the strength of an item trace accumulates if residual strength remains from the preceding rehearsal.

As can be seen in the two panels of the figure, these assumptions lead to items rehearsed at a fast rate having a greater trace strength over the same period of time as items rehearsed at a slow rate.

Our test of this proposed mechanism involved two converging operations. The first was based on the reasoning that if the age difference in memory was indeed produced by a slower rehearsal in older adults, then another factor that also affected speed of rehearsal should produce the same pattern of results as the age factor. We selected number of syllables per item as our other
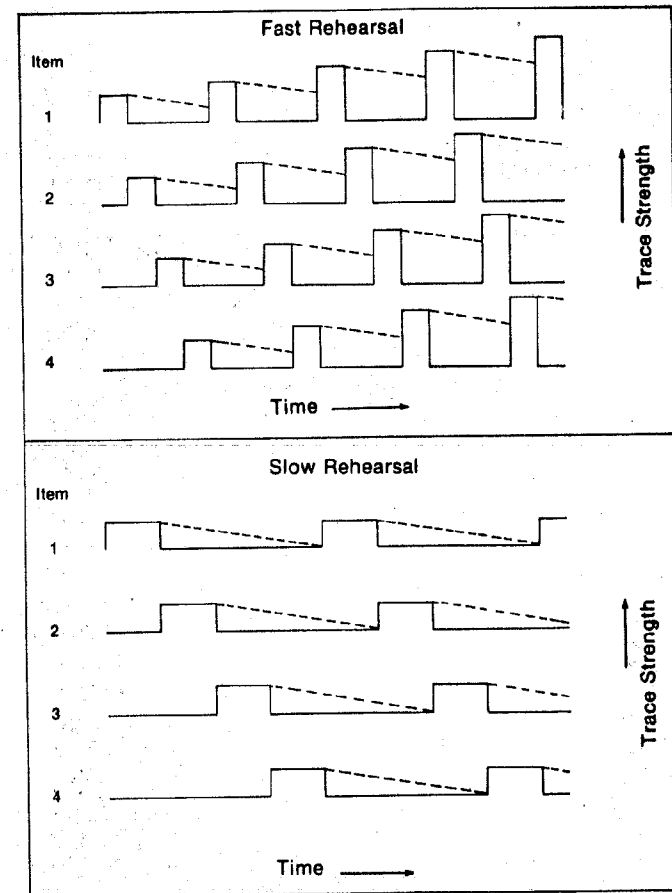
FIG. 2.2. Model of effects of rehearsal speed on memory trace strength.

factor, believing that three-syllable items would take longer to say or rehearse than one-syllable items. If rehearsal speed is the mechanism common to both the age and syllable factors, then the difference between three- and one-syllable words should be qualitatively similar, across the three serial position segments, to the difference between old and young adults.

The second operation that we utilized to test the rehearsal-speed explanation involved the measurement and comparison of rehearsal speed for young and old adults with one-syllable and three-syllable words. According to our hypothesis, measures of rehearsal speed should be faster for young subjects than for old subjects, and faster for one-syllable items than for three-syllable items.

An indirect measure of rehearsal speed was employed because of a suspicion that direct measures, such as those obtained from overt rehearsal procedures

(e.g., Rundus, 1971), might be particularly disruptive to the memory performance of the older subjects. The indirect procedure consisted of asking subjects to repeat items to themselves once, twice, or three times and then using the slope of the function relating rehearsal time to the number of rehearsals as the estimate of speed of rehearsal.

Sixteen females and eight males with a mean age of 22.8 years served as the young subjects, and 13 females and 11 males with a mean age of 71.1 years served as the old subjects. The mean years of education was 16.0 for the young subjects and 18.1 for the old subjects. The mean Wechsler Adult Intelligence Scale vocabulary raw scores were 63.6 for the young subjects and 70.4 for the old subjects. All subjects reported themselves to be in good health and were community residents.

Ninety-six one-syllable words and 96 three-syllable words were selected from the A category of the Thorndike–Lorge word frequency count. The words were taken from all parts of speech, and an attempt was made to equate the one- and three-syllable words on a subjective basis for imagery and association value. Twelve rehearsal lists of three words each and five memory lists of 12 words each were constructed with both the one-syllable and three-syllable words. The assignment of words to lists was varied across subjects in a balanced fashion.

The words were prepared on cards and presented in one field of a Gerbrands G-1130 three-field tachistoscope with automatic card changers. The presentation duration was 1.5 sec with a 2.0-sec interval between words. Unlimited time was allowed for recall at the end of each list, but most subjects took less than 1 min.

All subjects began the session with 12 rehearsal lists, six containing one-syllable words presented in alternation with six containing three-syllable words. Instructions stated that the three words in the list should be silently rehearsed one, two, or three times and then repeated aloud one time. A Hunter Klockounter Model 120-C was used to measure the time between the presentation of the third word in the list and the first overt repetition of a word from the list. Half of the subjects started with four trials of three covert repetitions, followed by four trials with two covert repetitions and four trials with one covert repetition. The other half of the subjects proceeded in the reverse order.

The one-syllable and three-syllable memory lists were presented alternately, with half of the subjects in each age group starting with the one-syllable words and half starting with the three-syllable words.

The remaining 12 rehearsal trials were administered following the last memory trial. The procedure was the same as in the first 12 trials except that the sequence of the number of covert repetitions for each subject was reversed.

An analysis of variance was conducted on the recall percentage data with age, number of syllables, and serial position segment (i.e., primacy—
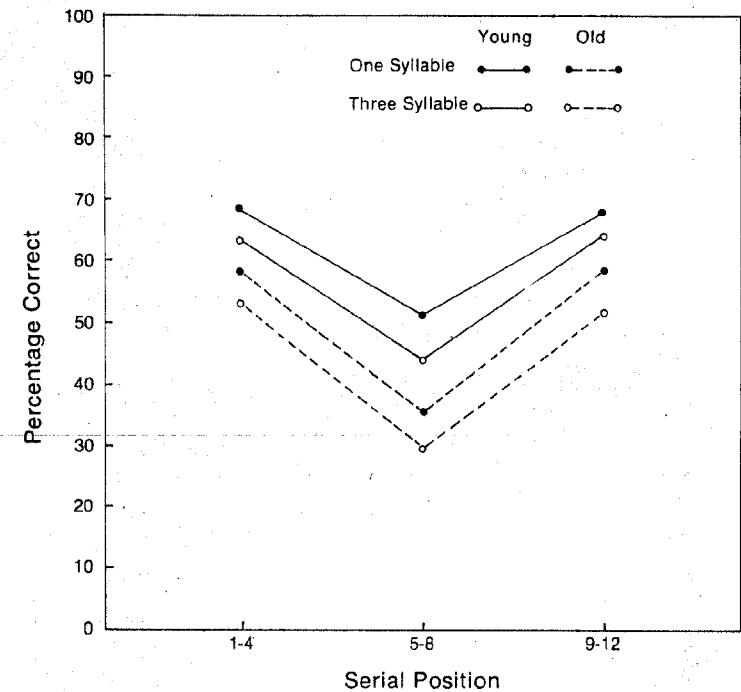
FIG. 2.3.   Percentage correct as a function of serial position.

positions 1 to 4, asymptote—positions 5 to 8, and recency—positions 9 to 12) as factors. All three main effects were significant [age, $F(1, 46) = 24.62$, $p < .01$; number of syllables, $F(1, 46) = 26.17$, $p < .01$; and segment, $F(2, 92) = 45.20$, $p < .01$], with no statistically significant interactions (i.e., all $Fs < 1.0$). The pattern is illustrated in Fig. 2.3. This figure in conjunction with the absence of an interaction between age and segment or between number of syllables and segment suggests that the age and syllable factors had very similar effects. Both factors lowered the overall level of recall, but did not change one segment of the serial position function more than any other segment.

Rehearsal time was measured as the slope of the least-squares regression line relating total rehearsal time to the number of rehearsals of the list. The fastest and the slowest times from the four trials with each number of rehearsals for one-syllable and three-syllable words were omitted to reduce variability. Since the lists consisted of three items each, the slope measures were divided by three to obtain rehearsal time per item. The mean rehearsal time per item and mean correlation coefficients indicating the fit of the regression functions to the data are displayed in Table 2.1. The excellent fits of the linear regression equations to the rehearsal time data suggest that

TABLE 2.1
Rehearsal Time Parameters

	Young	Old
Rehearsal Time per Item (in sec)		
One Syllable	.32	.43
Three Syllable	.37	.45
Correlation Coefficient[a]		
One Syllable	.96	.96
Three Syllable	.97	.95

[a]Mean correlations computed using the r-to-z transform.

subjects were following instructions and varying the number of subvocal rehearsals in the desired manner. This finding therefore supports the validity of the measures of rehearsal time. One indication of the reliability of these rehearsal time estimates can be obtained by examining the correlations across subjects for the rehearsal times of one- and three-syllable words. These correlations were + .79 for the young subjects and + .78 for the old subjects, suggesting a fairly high degree of consistency across the two estimates.

An analysis of variance conducted on the rehearsal-time measures revealed a significant effect of age [$F(1, 46) = 6.35, p < .01$] and number of syllables [$F(1, 46) = 8.21, p < .025$], but no interaction ($F < 1$).

The estimates in Table 2.1 are considerably slower than the estimates obtained by Clifton and Tash (1973) in a similar task, as their times were 185 msec and 260 msec for one-syllable and three-syllable words, respectively. One possible reason for this difference is that their subjects had received 10 previous sessions of experience with a much smaller set of stimuli (only 10 different words with each syllable number) than that employed here. The current data are in line with the rate of 3 items per sec mentioned by Sperling (1969) as being typical in memory experiments with unpracticed young subjects.

The rehearsal-speed hypothesis of age differences in memory is generally supported in these results as increased age and increased number of syllables had very similar effects on the rehearsal time measure and the recall percentage measure. An implication of these results is that older individuals have poorer memories because they are slow, i.e., they take longer to rehearse items than do younger individuals. This interpretation does not deny the existence of other factors also contributing to the age difference in memory— indeed, there is some evidence in the present study that older subjects are less adept at the strategy of recalling last input items first—but the interpretation does maintain that the major factor responsible for adult age differences in memory is a slower speed of rehearsal in older adults. According to this view,

therefore, the phenomenon of a 65-year-old college professor complaining of a failing memory is due to the same mechanism as that responsible for a 35-year-old athlete complaining of loss of eye–hand coordination.

CONCLUSION

The possibility that encoding, retrieval, and perhaps even storage deficits can be predicted from the speed-loss mechanism suggests that this interpretation of age-related memory problems has more generality than the memory-stage interpretation. Moreover, even if a stage analysis approach were successful at isolating the age difference in a single stage, no explanation of why the older adults are impaired in that stage and not some other stage would be available unless some fundamental mechanism such as age-related speed loss was postulated.

The similarity in the predictions from the two alternative research strategies illustrated above is undoubtedly partly a reflection of this author's bias, but the time required to perform simple mental operations does seem to be a reasonable candidate responsible for many individual differences in memory performance. In fact, if we accept the implication that the central nervous system is functioning at a slower rate in older adults, mental operation time may be the principal mechanism behind age differences in nearly all aspects of cognitive functioning. It certainly seems more reasonable and parsimonious to suggest that the elderly are doing the same things as the young but merely at a slower rate, than to suggest that for some unknown reason they have shifted to a strategy of utilizing less imagery, less organization, or less depth of encoding.

Since Birren's writings have obviously influenced the ideas that I have expressed here, it is perhaps appropriate to summarize these ideas in Birren's own words (1964):

> Clearly, it is overreaching at present to force all the facts of age changes in behavior into a single explanation involving the speed of a primary neural event. However there is an indication that many of the facts may be attributable to an age change in speed of neural activity [p. 128-129].

ACKNOWLEDGMENTS

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