Selective influences of age and speed on associative memory

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Data from three studies involving a continuous paired associates task performed by adults of different ages were analyzed in an attempt to identify how processing speed might mediate age-related differences in associative memory. Age differences were found in measures postulated to represent encoding and consolidation processes, but not in a measure presumed to reflect rate of forgetting. It is suggested that increased age is associated with a reduction in the speed of executing processes concerned with establishing a stable internal representation, but not with an alteration in the rate at which encoded information is lost as a function of time or subsequent processing.

Associative memory can be considered a fundamental cognitive process because much learning is based on the formation of associations, and processes of association are likely a key component in many other cognitive activities. A consistent finding in research on aging and cognition is that performance in various tests of associative memory is lower with increased age. For example, older adults typically perform worse than young adults in paired associate tests included in psychometric test batteries (e.g., Wechsler, 1987; Woodcock & Johnson, 1989). Large differences in paired associate performance by adults of different ages have also been documented in experimental research at least since Ruch (1934) and Gilbert (1935, 1941). Despite the convincing evidence of robust age differences in associative memory, a satisfactory explanation for this phenomenon is still lacking. (See Kausler, 1991, for a review.)

Evidence relevant to one factor that might be contributing to the age differences in associative memory is available in several recent studies from my laboratory. A study by Salthouse (1993b) involved the presentation of lists of six word pairs to 305 adults ranging between 19 and 84 years of age. Regression analyses revealed that age was associated with 16.2% of the variance when it was the only predictor of associative memory performance, but that it was associated with only 2.4% of the variance after the variance in Letter Comparison

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and Pattern Comparison measures of perceptual speed (see below) was controlled. Similar results were obtained in an unpublished study when 77 young adults (ages 19 to 26 years) and 69 older adults (ages 57 to 89 years) performed the same tasks. In that study, age was associated with 59.6% of the variance in associative memory accuracy when it was considered alone, but with only 6.9% of the variance after control of the speed measures.

Although results such as those just described suggest that speed appears to be involved in the relations between age and associative memory, they are not informative about the mechanisms responsible for that influence. For example, speed could exert its effects through less extensive elaboration of information at the time of original presentation, through more rapid forgetting between initial presentation and test, or by some other means. The mere discovery that the age-related effects are attenuated after statistical control of a speed measure does not allow these possibilities to be distinguished.

The research reported in this article was designed to investigate an interpretation of the influences of age and speed on associative memory based on a proposed distinction among processes of registration or encoding, consolidation, and forgetting. The basic assumption is that if the speed of many types of processing is slow, then the initial registration of the stimulus information may not be as elaborate and stable, and, consequently, the encoded information might be more easily disrupted by subsequent processing. However, after further consolidation has occurred, the rate of additional loss of information may not depend on the rate at which processing operations can be executed.

Measures of the three hypothesized processes can be derived by manipulating the number of items intervening between presentation and test in a continuous paired associate paradigm. The processes, and the measures postulated to represent them, are as follows: Registration and encoding is reflected by accuracy at lag 0 (i.e., no items intervening between presentation and test). These processes are assumed to have a high probability of success if presentation time is adequate, but because they require time, effectiveness of the operations is expected to be related to processing speed, especially when stimulus presentation time is limited. Consolidation is represented by the difference between performance at lag 0 and the first lag with any intervening items. That is, these processes can be inferred to be more effective when the accuracy difference between the two lags is small. Consolidation processes are assumed to be dependent on speed of processing, either directly because the speeds of these processes are related to a more general processing speed, or indirectly because less time is available for these processes when the initial registration and encoding processes are slow. Finally, forgetting is represented by the difference in performance between lag n and lag $n + 1$ when n is greater than 0. If forgetting is conceptualized as the loss of information attributable to the absence of processing (e.g., rehearsal), then no relation would be expected between speed of processing and rate of forgetting.

Although access and retrieval processes are not explicitly considered in this conceptualization, it is assumed that they are dependent on, and may interact with, the quality of the internal representation resulting from other processes. In other words, retrieval may be more effective when the encoding or elaboration is most extensive. An implication of this assumption is that encoding, consolidation, and forgetting processes may not be independent of retrieval processes. Nevertheless, the emphasis in this project was on early memorial processes, and the contribution of retrieval influences was presumed to be minimized by the use of a three-alternative forced-choice response format.

These are obviously not the only interpretations of the lag 0, lag 0 minus lag n, and lag n minus lag $n + 1$ measures. For example, because successive lags involve progressively more intervening items, the three measures could be interpreted as reflecting different amounts of interference. Alternatively, the first two measures could be viewed as reflecting processes of primary memory, and the third measure might be considered to reflect secondary memory processes.

The present assignment of theoretical processes to associative memory measures is admittedly speculative, but the encoding/consolidation/forgetting framework outlined above provides a basis for generating predictions about selective or differential influences of age and stimulus presentation time on the three measures. Moreover, because these predictions are not simply that age differences would increase with measures based on progressively longer lags, as might be the case from certain interpretations based on interference or primary memory/secondary memory conceptualizations, they provide a means of examining the plausibility of the different interpretations.

The assumptions described above lead directly to predictions regarding age-related effects on associative memory if it is further hypothesized that many of those effects are mediated through a slower rate of executing cognitive operations. Substantial age differences would be expected in the measure of the consolidation process, that is, the accuracy difference between lag 0 and the next shortest lag. Moderate age differences might also be expected in the measure of the registration/encoding process, that is, the accuracy at lag 0, particularly if stimulus presentation time is limited. And finally, few or no effects related to age would be expected in the measure of forgetting, that is, the accuracy difference between the two nonzero lags.

Initial data relevant to these predictions is available in two studies described in Salthouse (1994), each involving over 240 adults from a wide range of ages. The task in these studies was continuous associative memory involving word-digit pairs. The stimulus words were all different, but each word was randomly paired with one of three digits (i.e., 1, 2, or 3). Test items, consisting of the presentation of a word and the instruction to type the digit previously associated with it, occurred after zero, two, or four intervening items in the first study, and after zero, one, or two intervening items in the second study. All of the participants in these studies also performed the two paper-and-pencil perceptual speed tests used in the Salthouse (1993b) study, and two reaction time tasks derived from computer-administered versions of the Digit Symbol Substitution Test (see Salthouse, 1992b).

Because the primary focus in the Salthouse (1994) article was on interrelations of speed, study time, decision time, and decision accuracy in three different cognitive tasks, detailed analyses of the associative memory data were not reported in that article. Relevant analyses will therefore be described here before the design and results of the new study are discussed.

The major analytical procedure was a truncated hierarchical regression analysis in which the age-related variance in the criterion variable was determined when age was the only variable in the regression equation, and again when one or more other variables were controlled before entering age. The values therefore correspond to the square of the correlation (i.e., r^2 or R^2) for the age-associated variance with age alone, and to the square of the semi-partial correlation (i.e., sr^2) for the age-associated variance after control of other variables. Because subjects could control how long they studied the pairs, the variation in study time was partialed out before examining the age effects.

Results of the analyses, summarized in Table 1, show that there was relatively little age-related influence at lag 0 in either study (i.e., increment in R^2 associated with age of .019 and .032 for Studies 1 and 2, respectively). However, the age-related effects at the other lags were significant even after controlling the variance associated with performance at lag 0. It can therefore be concluded that there is a greater loss with increased age if any information intervenes between the presentation and the test. In contrast, there was no significant age-related variance in accuracy at lag 2 after the variance in accuracy

Table 1. Results of Salthouse (1994) studies

Variable	Lag 0	Lag 2	Lag 4
Study 1 (n = 246)			
% Correct			
Mean	92.4	55.3	55.6
SD	12.7	21.6	17.7
sr^2 associated with age after control of study time			
Alone	.019	.075*	.064*
After lag 0	—	.060*	.063*
After lag 2	—	—	.042*
After lags 0 and 2	—	—	.042*
After P&P PSpeed	.001	.008	.031*
After RT Speed	.003	.014	.032*

	Lag 0	Lag 1	Lag 2
Study 2 (n = 258)			
% Correct			
Mean	94.6	77.0	69.1
SD	9.9	22.0	20.7
sr^2 associated with age after control of study time			
Alone	.032*	.073*	.062*
After lag 0	—	.040*	.047*
After lag 1	—	—	.015
After lags 0 and 1	—	—	.015
After P&P PSpeed	.005	.015	.011
After RT Speed	.000	.006	.005

Note. P&P PSpeed is a composite of performance in the Letter Comparison and Pattern Comparison Tests; RT Speed is a composite of performance on the Digit Digit and Digit Symbol reaction time tasks.
* $p < .01$.

at lag 1 was controlled in Study 2. (The age-related variance in lag 4 after control of lag 2 was significant in Study 1, but interpretation of these data is complicated because some of the intervening items in that condition consisted of tests of other lags rather than merely additional word-digit pairs.)

More direct support for the predictions is provided from results of analyses on difference scores representing the consolidation (lag 0 minus lag 2 for Study 1, and lag 0 minus lag 1 for Study 2) and forgetting (lag 2 minus lag 4 for Study 1, and lag 1 minus lag 2 for Study 2) processes. In neither study was there a significant age relation on the forgetting scores (i.e., increment in R^2 associated with age of .004 in Study 1, and .001 in Study 2). However, in both studies the age-related variance was significantly greater than zero for the consolidation scores (i.e., increment in R^2 for age of .036 in Study 1, and .045 in Study 2).

The results of the Salthouse (1994) studies are therefore generally consistent with the predictions outlined above. There were slight age-related differences in the lag 0 measure postulated to reflect registration or encoding of the items, and substantial differences in the difference between lag 0 and lag 1 hypothesized to reflect consolidation of information. However, there were little or no age differences in the rate of loss with additional items (difference between lag 1 and lag 2). It is also apparent in Table 1 that the age-related variance at each lag was appreciably reduced after statistical control of the perceptual speed or reaction time speed measures. Discussion of this finding will be deferred until after the results of the new study are reported.

The present study had two primary purposes: (a) to attempt to replicate the results just described with respect to differential age sensitivity on the three hypothesized components (i.e., large age effects were expected on the consolidation measure, small to moderate effects expected on the registration/encoding measure, and no age effects expected on the forgetting measure); and (b) to investigate the effects of restricted presentation time on the three measures. If the speculations discussed above are valid, then the registration/encoding (lag 0), and consolidation (lag 0 minus lag 1) measures should be more affected by limitations of stimulus presentation time than the forgetting (lag 1 minus lag 2) measure. Finally, to examine the nature of the speed influence, tests postulated to represent motor speed (i.e., Boxes and Digit Copying) were administered to all research participants in addition to tests representing perceptual speed.

EXPERIMENT

METHOD

Participants

Characteristics of the 50 young adults and 50 older adults who participated in this study are summarized in Table 2. The young adults were recruited from psychology classes, and were compensated with credit toward a course

Table 2. Demographic characteristics of research participants and means and standard deviations on the vocabulary and speed tests

Variable	Young (n = 50)	Old (n = 50)	t
Age (years)	20.3 (1.4)	68.7 (6.0)	55.92*
% Females	36	46	
Education (years)	14.5 (1.1)	15.1 (2.3)	1.52
Health rating	1.7 (0.6)	2.0 (0.8)	1.72
Tests			
Vocabulary			
Synonyms	4.9 (2.0)	8.1 (2.3)	7.26*
Antonyms	4.4 (2.1)	6.8 (2.9)	4.65*
Boxes	66.0 (12.9)	47.8 (11.6)	−7.42*
Digit Copy	57.5 (6.5)	46.4 (10.6)	−6.30*
Letter Comparison	12.2 (2.4)	8.6 (2.6)	−7.23*
Pattern Comparison	20.6 (3.4)	13.7 (3.0)	−10.75*
Digit Digit			
RT (ms)	580 (74)	885 (292)	7.16*
Accuracy (% correct)	97.4 (2.4)	97.5 (2.2)	0.19
Digit Symbol			
RT (ms)	1089 (147)	1732 (363)	11.62*
Accuracy (% correct)	96.7 (2.2)	97.2 (2.1)	0.97

Note. Health is a self-rating on a scale ranging from 1 (*excellent*) to 5 (*poor*). Scores on the Vocabulary, Boxes, and Digit Copying Tests are number correct; scores on the Letter Comparison and Pattern Comparison Tests are number correct minus number incorrect. RT = reaction time. *SD*s in parentheses.
* $p < .01$.

requirement. Older adults were recruited from newspaper advertisements, and received $10 for their travel and participation.

Procedure

All participants performed the same battery of paper-and-pencil and computer-administered tests in the same order. The order of the paper-and-pencil tests was Boxes, Pattern Comparison, Letter Comparison, Digit Copying, Antonym Vocabulary, and Synonym Vocabulary.

Each of the first four tests consisted of an instruction page containing several examples, followed by two test pages. Participants were allowed 30 s to complete as many of the items as possible on each test page, and the score for the test was the average across the two pages. Stimuli in the Boxes Test consisted of three lines forming three sides of a square. The participants' task was to draw a fourth line on each item to create a square or box. Items in the Pattern Comparison Test consisted of pairs of line patterns composed of either three, six, or nine line segments. The task was to write an *S* (for *same*) between the two patterns if they were identical, and to write a *D* (for *different*) if they were not identical. One-half of the pattern pairs were different because of a shift in the position of one line segment in one member of the pair. Letter Comparison Test items consisted of pairs of either three, six, or nine letters. As in the Pattern Comparison Test, the participants wrote an *S* (for *same*) when the two members of the pair were identical, and wrote a *D* (for *different*) when they were not. One-half of the letter sets were different because of a difference in the identity of one letter in one member of the pair. The Digit Copying Test consisted of pairs of boxes with a digit in the top box and nothing in the bottom box. The task was to copy the digit in the box below it.

The vocabulary tests were 5-alternative multiple choice tests with 10 antonym items and 10 synonym items. The items were selected from those of intermediate difficulty in a project by Salthouse (1993a), and 2 min was allowed for each test.

The first two computer-administered tests were designed to assess reaction time speed. Both tests were modifications of the Digit Symbol Substitution Test (see Salthouse, 1992b) and required *same/different* responses to pairs of visually presented stimuli. In the Digit Symbol Test a code table containing pairs of digits and symbols was displayed at the top of the screen, and stimulus items consisting of a digit and a symbol were presented in the middle of the screen. The task was to press the slash (/) key as rapidly as possible if the digit and symbol matched according to the code table, and to press the *Z* key as rapidly as possible if they did not match. The Digit Digit Test was similar but the code table contained two identical rows of digits, and the stimulus items consisted of a pair of digits. Because decisions in this test were based on physical identity rather than associational equivalence, the code table was superfluous and was presented merely to maximize physical resemblance to the Digit Symbol Test. Participants completed a practice set of 18 trials before doing the experimental set of 90 trials in each test.

The Associative Memory Test consisted of the presentation of words paired with a digit between 1 and 3. Each block of trials contained 66 word-digit pairs, and eight probes each with lags of 0, 1, and 2. Probes consisted of the presentation of the stimulus word along with the instruction to type the digit that had previously been paired with that word. Participants could take as long as they wanted to enter their response, but the presentation time for the word-digit pairs varied across trial blocks. In the first block the duration of the stimulus pairs was under the participant's control because a key had to be pressed after each pair. Presentation times per pair in the remaining six blocks were 1.5 s, 1.0 s., 0.5 s, 0.5 s, 1.0 s, and 1.5 s, respectively. Different stimulus words, nouns selected from a children's dictionary to ensure at least moderate familiarity for most people, were used in each block of trials. Intervening items in all lags consisted only of word-digit pairs (i.e., no tests of other lags occurred during the presentation-test interval for a given lag).

RESULTS

Means and standard deviations of the vocabulary and speed tests are presented in Table 2. As is typically found in research comparing groups of this type, older adults had higher scores on the vocabulary tests but slower performance on the speed tests than young adults (e.g., Salthouse, 1993a).

Because the correlations between tests presumed to measure the same speed construct were high, composite speed measures were created. That is, a composite motor speed index was formed by averaging the *z* scores from the Boxes and Digit Copying ($r = .76$) measures, a composite perceptual speed index was formed by averaging the *z* scores from the Letter Comparison and Pattern Comparison ($r = .67$) measures, and a composite reaction time speed index was formed by averaging the *z* scores from the Digit Digit and Digit Symbol ($r = .76$) measures.

Accuracy in each age group as a function of stimulus presentation time and lag between presentation and test is displayed in Figure 1. Notice that in both groups accuracy was similar in the 1.5 s and self-paced conditions, although the duration spent inspecting the stimulus pairs in the self-paced condition was much longer for older adults than for young adults. A 2 × 4 × 3 (Age × Time × Lag) analysis of variance (ANOVA) on the accuracy data revealed that all main effects and interactions were significant, all $Fs > 3.6$, $p < .02$, except for the triple interaction, $F(6, 588) = 1.67$.

Results of hierarchical regression analyses similar to those described above, with actual chronological age as the primary predictor variable, are summarized in Table 3. Four major findings should be noted. First, the age-related variance (i.e., r^2 for age alone) was significant at all lags and presentation times, except where an obvious measurement ceiling existed (i.e., lag 0 with self-paced presentations). Second, in all cases the age-related variance in accuracy (i.e., the sr^2 corresponding to the increment in variance associated with age after control of other variables) at lags 1 and 2 remained significant after controlling the variance in accuracy at lag 0. At least some of the age-related variance in accuracy when other information intervenes between presentation and test is therefore independent of the variance in initial accuracy. Third, when accuracy at lag 1 is controlled, the age-related effects in accuracy at lag 2 are greatly reduced, and in all but one case (1.0 s) not significantly different from zero. This finding implies that there is little difference between the two age groups in the loss in accuracy from one to two intervening items. Fourth, the age-related variance in all of the measures is substantially reduced when the

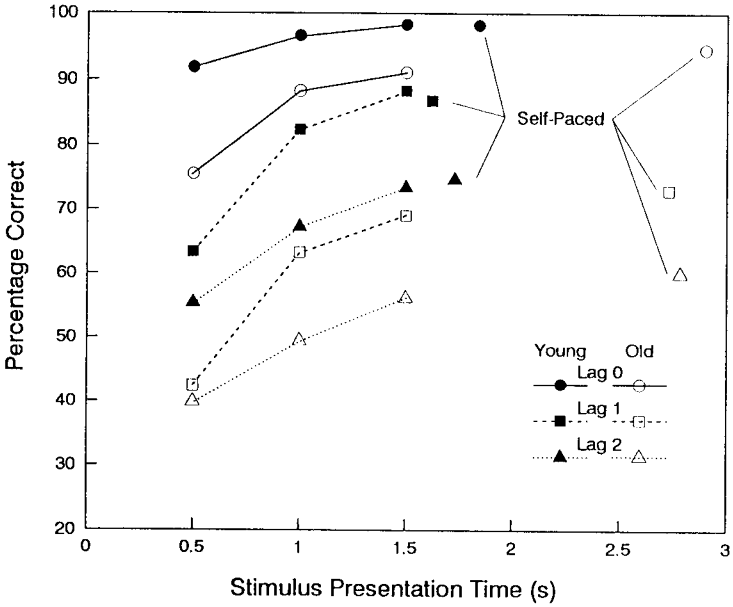

Figure 1. Mean percentage correct for young and old adults as a function of stimulus presentation time and lag between presentation and test

composite speed measures are controlled. Furthermore, the reduction in age-related variance was greater after control of the perceptual speed index than after control of the motor speed index in 11 of the 12 cases. In almost all respects, these results are similar to those reported in Table 1.

Age × Time ANOVAs were also conducted on the measures of the hypothesized components: that is, lag 0 for registration and encoding; the difference between lag 0 and lag 1 for consolidation; and the difference between lag 1 and lag 2 for forgetting. All three effects were significant ($p < .01$) in the analysis of the lag 0 measure: age, $F(1, 98) = 33.49$, $MSE = 233.59$; time, $F(3, 294) = 50.06$, $MSE = 63.96$; and Age × Time, $F(3, 294) = 11.23$. The patterns with this variable are displayed in Figure 1, where it can be seen that the age differences were smaller with longer times as the average accuracies approach the maximum possible value. Only the main effects of age, $F(1, 98) = 19.42$, $MSE = 461.32$, and time, $F(3, 294) = 23.61$, $MSE = 200.97$, were significant with the lag 0 minus lag 1 difference score. Means at each time for this variable were 16.5 for self-paced, 16.0 for 1.5 s, 19.6 for 1.0 s, and 30.8 for 0.5 s. The time effect therefore reflects a pattern of larger difference scores at shorter presentation

Table 3. Proportion of age-related variance in associative memory accuracy

Variable	Lag 0	Lag 1	Lag 2	Lag 0	Lag 1	Lag 2
	Self-paced			1.5 s		
% Correct						
Mean	96.4	79.9	67.3	94.7	78.7	64.7
SD	7.5	20.3	22.9	9.9	18.4	18.4
Proportion of variance associated with age						
r^2 for age						
Alone	.056	.114*	.108*	.147*	.281*	.222*
sr^2 for age						
After lag 0	—	.058*	.059*	—	.123*	.159*
After lag 1	—	—	.030	—	—	.024
After lags 0 and 1	—	—	.024	—	—	.029
After P&P MSpeed	.008	.021	.029	.069*	.181*	.176*
After P&P PSpeed	.000	.005	.032	.016	.091*	.044
After RT Speed	.000	.042	.047	.001	.086*	.102*
	1.0 s			0.5 s		
% Correct						
Mean	92.4	72.8	58.3	83.7	52.9	47.6
SD	11.4	19.7	18.6	15.4	20.3	17.8
Proportion of variance associated with age						
r^2 for age						
Alone	.140*	.236*	.268*	.304*	.265*	.207*
sr^2 for age						
After lag 0	—	.076*	.157*	—	.080*	.092*
After lag 1	—	—	.058*	—	—	.029
After lags 0 and 1	—	—	.058*	—	—	.024
After P&P MSpeed	.046	.108*	.078*	.153*	.153*	.079*
After P&P PSpeed	.008	.051	.048	.077*	.030	.020
After RT Speed	.010	.033	.086*	.074*	.060*	.035

Note. P&P MSpeed is a composite of performance in the Boxes and Digit Copying Tests, P&P PSpeed is a composite of performance in the Letter Comparison and Pattern Comparison Tests, and RT Speed is a composite of performance on the Digit Digit and Digit Symbol reaction time tasks.
* $p < .01$.

times. The only significant effect with the lag 1 minus lag 2 difference score was time, $F(3, 294) = 6.52$, $MSE = 278.03$. Means at each time were 12.6 for self-paced, 14.0 for 1.5 s, 14.5 for 1.0 s, and 5.3 for 0.5 s. The relatively low levels of accuracy for lag 2 at 0.5 s (i.e., average of 47.6%) suggest that the range of the lag 1 minus lag 2 difference score at the shortest time may have been restricted because of a measurement floor (i.e., chance was 33%).

The presentation time effects in these measures were more complicated than expected. As predicted, the consolidation measure (lag 0 minus lag 1) increased as presentation time decreased. However, a measurement ceiling in the registration/encoding measure (lag 0) and a possible measurement floor in the forgetting measure (lag 1 minus lag 2) make it difficult to interpret the patterns with those variables.

Because of the interest in the selective influence of age on the difference score measures, additional analyses were conducted on these two variables. A t test on the average difference score across all presentation times for young and old adults was significant with the lag 0 minus lag 1 (consolidation) difference, $t = 4.41$; the observed effect size (d) was .88. The age difference with the lag 1 minus lag 2 difference (forgetting) score was in the opposite direction and was not significant, $t = -0.95$. Power analyses revealed that the power to detect an effect of $d = .88$ on the lag 1 minus lag 2 difference score was .99 and that the power to detect an effect of one-half this magnitude was .59.

One possible reason for the weaker age relations on the lag 1 minus lag 2 difference score is that its reliability may have been lower than the lag 0 minus lag 1 difference score. The reliability of each difference score was therefore estimated by determining the correlation between the average difference scores across the presentation times of 0.5, 1.0, and 1.5 s for the first and second blocks of trials, and then boosting this correlation by the Spearman-Brown formula to estimate the reliability of the overall score. The estimated reliability was .74 for the lag 0 minus lag 1 difference score, and only .41 for the lag 1 minus lag 2 difference score. To assess the consequences of these reliability differences, the correlations between age and the difference scores were adjusted for the unreliability of the difference scores. The original correlation between age and the lag 0 minus lag 1 measure was .39 and it increased to .45 after adjustment. The original correlation between age and the lag 1 minus lag 2 measure was −.06, and it increased to −.09 after adjustment. Both the power analyses and the correction for attenuation because of unreliability therefore suggest that the lack of a significant age difference in the lag 1 minus lag 2 difference score measure is not simply an artifact of weak or insensitive measurement.

DISCUSSION

As in other studies, the results of the analyses of the three data sets reported here indicate that a moderate to large proportion of the age-related variance in measures of associative memory is shared with measures of processing speed. For example, after statistical control of the paper-and-pencil composite measure of perceptual speed, the R^2 associated with age at lag 2 was reduced 89%, that is, (.075 − .008)/.075 in Study 1 and 79% in Study 2 of Salthouse (1994), and between 70% and 90% across stimulus presentation conditions in the present experiment. Because effects of this magnitude could not occur if the speed measure were not related both to the associative memory measure and to age, it can be inferred that processing speed, or whatever else is reflected by the speed measures, contributes to the age-related differences in associative memory.

The data from these studies are also informative about the mechanism by which speed contributes to the mediation of adult age differences in associative memory. Based on the results of the analyses reported here, it appears that age-related effects are pronounced only at the earliest stages of encoding and consolidation, as reflected in accuracy with lags of 0 and 1. Little or no age differences are evident in the rate at which information is lost with additional time or intervening information.

Other research also supports the conclusion that age-related influences on the rate of forgetting over short intervals are small to nonexistent. For example, the functions relating decision accuracy to the number of intervening items in continuous recognition tasks have been found to be similar in adults of different ages (e.g., Craik, 1971; Erber, 1978; Ferris, Crook, Clark, McCarthy, & Rae, 1980; Flicker, Ferris, Crook, & Bartus, 1989; LeBreck & Baron, 1987; Lehman & Mellinger, 1986; Poon & Fozard, 1980; Wickelgren, 1975). Rates of information loss have also been found to be similar in young and old adults in tasks in which the amount or duration of activity between presentation and test is varied (e.g., Charness, 1981; Dobbs & Rule, 1989; Keevil-Rogers & Schnore, 1969; Kriauncìunas, 1968; Puckett & Lawson, 1989; Puckett & Stockburger, 1988; Ryan & Butters, 1980; Salthouse, 1992a; Talland, 1967).

What is responsible for the age-related effects found in measures hypothesized to reflect registration/encoding and consolidation processes? This question can be addressed at two different levels. At a functional level, it can be hypothesized that there is a limited window of opportunity in which the relevant processing can be carried out, and if the speed of processing is too slow, then the quality of the product of that processing will be impaired. That is, encoding and consolidation operations can be conceptualized as working on information that, either because of decay or displacement, is degrading over time in quality, quantity, or both. Only if those processes can be performed rapidly, therefore, will the information upon which they are based still be accurate and complete enough to result in a stable representation.

Another level of explanation is neurophysiological. A possible mechanism at this level is the duration required for a pattern of neural activation to settle into a relatively stable configuration. For example, encoding and consolidation processes might correspond to the integration of activation induced by the external stimulus with activation corresponding to internal associations and elaborations. If the time required to achieve this integration is long, then its successful completion is jeopardized by subsequent processing.

Both of these possibilities need to be investigated with further research before their plausibility can be adequately evaluated. Nevertheless, the discovery of selective and differential age-related influences in associative memory imposes important constraints on the types of viable explanations for this phenomenon. In particular, the results reported here strongly imply that an adequate interpretation of age differences in associative memory should incorporate linkages among age, processing speed, and the effectiveness of initial encoding or consolidation of associative information.

Notes

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References

Charness, N. (1981). Visual short-term memory and aging in chess players. *Journal of Gerontology, 36,* 615–619.

Craik, F. I. M. (1971). Age differences in recognition memory. *Quarterly Journal of Experimental Psychology, 23,* 316–323.

Dobbs, A. R., & Rule, B. G. (1989). Adult age differences in working memory. *Psychology and Aging, 4,* 500–503.

Erber, J. T. (1978). Age differences in a controlled-lag recognition memory task. *Experimental Aging Research, 4,* 195–205.

Ferris, S. H., Crook, T., Clark, E., McCarthy, M., & Rae, D. (1980). Facial recognition memory deficits in normal aging and senile dementia. *Journal of Gerontology, 35,* 707–714.

Flicker, C., Ferris, S. H., Crook, T., & Bartus, R. T. (1989). Age differences in the vulnerability of facial recognition memory to proactive interference. *Experimental Aging Research, 15,* 189–194.

Gilbert, J. G. (1935). Mental efficiency in senescence. *Archives of Psychology* (27, Whole No. 188).

Gilbert, J. G. (1941). Memory loss in senescence. *Journal of Abnormal and Social Psychology, 36,* 73–86.

Kausler, D. H. (1991). *Experimental psychology, cognition, and human aging.* New York: Springer-Verlag.

Keevil-Rogers, P., & Schnore, M. M. (1969). Short-term memory as a function of age in persons of above average intelligence. *Journal of Gerontology, 24,* 184–188.

Kriauciunas, R. (1968). The relationship of age and retention-interval activity in short-term memory. *Journal of Gerontology, 23,* 169–173.

LeBreck, D. B., & Baron, A. (1987). Age and practice effects in continuous recognition memory. *Journal of Gerontology, 42,* 89–91.

Lehman, E. B., & Mellinger, J. C. (1986). Forgetting rates in modality memory for young, mid-life, and older women. *Psychology and Aging, 1,* 178–179.

Poon, L. W., & Fozard, J. L. (1980). Age and word frequency effects in continuous recognition memory. *Journal of Gerontology, 35,* 77–86.

Puckett, J. M., & Lawson, W. M. (1989). Absence of age differences in forgetting in the Brown-Peterson task. *Acta Psychologica, 72,* 159–175.

Puckett, J. M., & Stockburger, D. W. (1988). Absence of age-related proneness to short-term retroactive interference in the absence of rehearsal. *Psychology and Aging, 3,* 342–347.

Ruch, F. L. (1934). The differentiative effects of age upon human learning. *Journal of General Psychology, 11,* 261–285.

Ryan, E., & Butters, N. (1980). Learning and memory impairments in young and old alcoholics: Evidence for the premature-aging hypothesis. *Alcoholism: Clinical and Experimental Research, 4,* 288–293.

Salthouse, T. A. (1992a). Influence of processing speed on adult age differences in working memory. *Acta Psychologica, 79,* 155–170.

Salthouse, T. A. (1992b). What do adult age differences in the Digit Symbol Substitution Test reflect? *Journal of Gerontology: Psychological Sciences, 47,* P121–P128.

Salthouse, T. A. (1993a). Speed and knowledge as determinants of adult age differences in verbal tasks. *Journal of Gerontology: Psychological Sciences, 48,* P29–P36.

Salthouse, T. A. (1993b). Speed mediation of adult age differences in cognition. *Developmental Psychology, 29,* 722–738.

Salthouse, T. A. (1994). The nature of the influence of speed on adult age differences in cognition. *Developmental Psychology, 30,* 240–259.

Talland, G. A. (1967). Age and the immediate memory span. *The Gerontologist, 7,* 4–9.

Wechsler, D. (1987). *Manual for Wechsler Memory Scale* (Rev. ed.). New York: Psychological Corp.

Wickelgren, W. A. (1975). Age and storage dynamics in continuous recognition memory. *Developmental Psychology, 11,* 165–169.

Woodcock, R. W., & Johnson, M. B. (1989). *Woodcock-Johnson Psycho-Educational Battery* (Rev. ed.). Allen, TX: DLM Teaching Resources.