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General and Specific Speed Mediation of Adult Age Differences in Memory

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The proposal that age-related differences in some measures of speed of performance may not be independent of the age-related differences in other measures of speed of performance has been associated with considerable controversy. Because converging evidence can often resolve this type of controversy, correlation-based procedures are proposed to distinguish general (or common) and specific (or unique) age-related influences on measures of speeded performance. Results from three earlier studies and from a new study suggest that a large proportion of the age-related variance in a wide range of speed measures is shared and is not distinct. Furthermore, the common or general speed factor appears to play an important role in the mediation of age-related differences in memory.

NEGATIVE relations between age and measures of episodic memory performance are well documented (e.g., Craik & Jennings, 1992; Hultsch & Dixon, 1990; Kausler, 1994; Salthouse, 1991), as are negative relations between age and various measures of processing speed (e.g., Salthouse, 1985; Cerella, 1990). However, recent research has revealed that the two sets of age relations are not independent because statistical control of the presumably simpler speed measures leads to a large reduction in the age-related variance in measures of memory.

This phenomenon can be illustrated with data from a study recently reported by Salthouse (1993a) in which 305 adults from a wide range of ages attempted to remember two lists of 12 words each, and also performed two speeded paper-and-pencil perceptual comparison tasks involving pairs of letters or pairs of line patterns. All measures were converted to z-scores, and then the two paper-and-pencil perceptual speed measures were averaged to form a composite perceptual speed measure, and the recall accuracy scores on the two lists were averaged to form a composite memory measure. The age-related variance in the recall memory score was .162, but it was reduced nearly 84%, to .026, after the perceptual comparison speed measure was controlled.

This same pattern of attenuated age-related effects after control of speed has been observed in a variety of other memory measures in a number of studies in my laboratory (e.g., Salthouse, 1994b, 1994c, 1995; Salthouse & Babcock, 1991; Salthouse, Fristoe, & Rhee, in press), and in studies from other researchers (e.g., Bors & Forrin, in press; Hultsch, Hertzog, & Dixon, 1990; Park et al., 1994). Furthermore, the results have been consistent across experimenter-paced and subject-paced memory tasks, across tasks involving verbal and spatial information and across different types of experimental procedures (e.g., free recall, paired associates).

Because the perceptual comparison tasks used in these studies are very simple, I have hypothesized that the speed influence occurs because the paper-and-pencil speed measures index a fairly general processing speed factor that decreases with increased age. The perceptual speed measures are therefore assumed to reflect the speed with which many operations, including those directly relevant to memory functioning, can be carried out. An implication of this assumption is that a large amount of the age-related variance across many different speed measures will be shared. A major purpose of the current study is to investigate this implication by examining the fit of a structural equation model with a single latent speed construct related to all of the individual speed measures and with relations from age to the latent speed construct and to each individual speed measure (cf., Kliegl & Mayr, 1992; McArdle & Prescott, 1992; Salthouse, 1994a). The hypothesis of a general speed factor would be supported if there is a good fit of the data to a model in which the latent speed construct has strong relations to the individual speed measures, but those measures have only weak direct relations from age.

The speed measures examined in the current study were designed to involve different types of information (i.e., alphanumeric, verbal, and spatial), different modes of stimulus presentation (i.e., computer-administered visual displays, printed, and auditory), and different modes of response (i.e., manual reaction time, written, and vocal). In addition to measures hypothesized to represent general processing speed, measures designed to reflect the speed of specific memory-relevant processes such as search, rehearsal, association, reorganization, and retrieval were also included. If those measures are more directly related to the functioning of memory than other speed measures, they might be expected to have strong relations to the measures of memory, but possibly weak relations to the hypothesized general factor.

Two analyses were also conducted to examine the degree of independence of age-related influences on measures hypothesized to reflect the speed of specific processes. A total of nine derived measures that could be postulated to represent the time for specific cognitive operations were investigated. For example, a measure of substitution time was derived from the difference between the average of letter-symbol and symbol-letter reaction time and the average of letter-letter and symbol-symbol reaction time. That is, in the first two tasks the choice decision required determining the correspondence between letters and symbols, whereas in the latter two tasks the decision was based on physical identity, and hence the difference between the two variables could be interpreted as a measure of the time to associate or substitute letters and symbols. Other specific speed measures were the intercept and slope of the regression equation relating reaction time to set size in a memory search task, the time to reorganize information in memory, the time to name two syllables, interference in color naming, facilitation in color naming, and the additional time required to count backwards by small (3) or large (7) numbers.

One analytical procedure with these measures consisted of comparing the age-related variance in the presumably specific derived score before and after statistical control of the variance in the hypothesized general speed factor. Results of this procedure should indicate the extent to which age-related influences on the measures assumed to reflect specific processes are independent of more general age-related effects.

The second analytical procedure was designed to determine the degree to which the age-related influences on the more complex measure, with the greater processing requirement, were independent of the age-related influences on the simpler measure. For example, the analyses were used to determine the degree to which the age-related influences in the average of the letter-symbol and symbol-letter reaction time measures were independent of those in the average of the letter-letter and symbol-symbol reaction time measures. The rationale for this procedure was discussed by Salthouse and Coon (1994), and it can be viewed as a means of examining selective age-related effects without the limitations associated with difference score measures.

Finally, the relations of the speed measures to measures of memory were examined in a structural equation model and in a series of hierarchical regression analyses. The primary measures of memory consisted of the number of items recalled from free recall tasks involving 10 unrelated words. In addition, accuracy values in a letter memory task and in a memory search task with interpolated activity between the memory set and the probe also served as secondary measures of memory. It was anticipated that earlier results would be replicated, such that there would be considerable reduction of the age-related variance in the memory measures after control of the measures of speed. Of particular interest was whether the reduction in age-related variance would be greater with speed measures assumed to represent processes relevant to memory functioning. Finally, in order to determine whether the relations to speed might be greater when the memory stimuli are presented at a more rapid rate, three different rates of stimulus presentation were used in the free recall memory task.

METHOD

Subjects. — Participants in this study consisted of 172 adults between 18 and 93 years of age. (Data from 6 additional participants were omitted from the analyses because of missing values on several of the measures.) Demographic characteristics of the participants, divided into three age groups for ease of description, are summarized in Table 1. Notice that most participants rated their health between good (3) and excellent (1), and that the average participant had attended about one year of college. Amount of education was negatively related to age, but at least one measure of verbal ability, synonym vocabulary score, was positively related to age.

Procedure. — All participants performed the tasks in the following order: number matching, pattern matching, pattern comparison, letter comparison, word copying, word retrieval, vocabulary, Stroop color-word, naming speed, counting backwards, sequential associates, free recall, memory search, reaction time, and serial memory. Details of the tasks are described below.

The criterion task was a *free recall memory* task involving two 10-word lists each at stimulus presentation rates of .5, 1, or 2 sec per word. After a practice trial involving eight words presented at a 3-sec rate, the lists were presented on a computer monitor at rates of 2 sec, 1 sec, .5 sec, .5 sec, 1 sec, and 2 sec. At the end of the list the participant was allowed 1 min to write as many words as he or she could remember in any order. All lists consisted of two-syllable words between five and seven letters in length from Cluster 8 (high in all dimensions) of the Toglia and Battig (1978) norms. In addition, all words had a frequency of at least 20 per million according to the Thorndike (1944) word frequency count. The primary measures of performance were the numbers of items recalled at each of the three presentation rates.

Several of the speed tasks were designed to assess the speed of processes presumed to be directly relevant to memory functioning. One was a modified Sternberg *memory search* task involving letter stimuli in a varied mapping condition. Two blocks of 48 trials each were presented, with 6 positive trials and 6 negative trials each for set-sizes 1 through 4. The experimental trials were preceded by a practice block of 8 trials, containing 1 trial at each combination of set-size and decision type. During the interval between the presentation of the memory set and the display of the probe stimulus a series of five randomly selected digits (from 0 to 9) was presented. The research participant was instructed to press the "Z" key if the digit was odd and to press the "/" key if the digit was even, and to do this for each of the interpolated digits. The requirement to perform

Table 1. Demographic Characteristics of Research Participants (n = 172)

	18–39		40–59		60–93		
	Mean	*SD*	Mean	*SD*	Mean	*SD*	Age *r*
n	69		39		64		
Age	28.1	6.5	48.0	5.7	70.4	8.2	
% Female	63.8		64.1		71.9		
Education	13.9	2.1	13.6	2.0	13.0	2.7	−.20*
Health	1.9	0.7	2.2	0.9	2.3	0.9	.23*
Vocabulary							
Synonym	4.0	2.7	4.8	2.4	6.0	3.3	.24*
Antonym	3.7	2.7	4.2	3.0	4.6	3.2	.10

*$p < .01$.

five odd/even classification responses during the interval between the memory set items and the probe was designed to maximize the involvement of secondary memory in the task. The reaction time and accuracy to the probe stimulus at each memory set size were the primary measures of performance, although the slope and the intercept of the function relating reaction time to the number of items in the memory set were also computed.

A measure of rehearsal or articulation speed was obtained from the *naming speed* task. In this task two lists of 10 one-syllable or three-syllable words were to be read as quickly as possible. The lists were printed on a sheet of paper, and the examiner timed the responses with a stop watch. All of the words were from Cluster 8 of the Toglia and Battig (1978) norms and were arranged in lists of 10 one-syllable and 10 three-syllable words. The measure of performance was the average time required to name one-syllable and three-syllable words (i.e., the total time divided by 10), which can be hypothesized to serve as an index of articulation or rehearsal rate.

The time required to reorganize information in memory was determined from a *serial recall* task involving four letters (Salthouse & Coon, 1993). Each trial in the task consisted of the presentation of a list of four letters, and at the end of the sequence an instruction indicated whether the letters were to be recalled (by typing the letters) in the original order or in alphabetic order. Two blocks of 16 trials each were presented, with eight trials in each block requiring recall in the original order and eight trials requiring recall in alphabetic order. The trials within a block were randomly intermixed such that the research participant did not know about the order of recall until the presentation of the recall instruction at the end of the list. A practice block of six trials preceded the experimental trials. The primary measure of performance in this task was the difference in the recall time for correctly recalled sequences in the two conditions, which can be postulated to reflect the time needed to carry out the relevant (re-ordering or transformation) processing. The number of trials with correct recall was also used as another measure of memory effectiveness.

A *word copying* task required participants to copy a list of words as rapidly as possible. Two lists of 24 words each were presented, and 30 sec were allowed for the participant to copy as many of the words as possible. The primary measure of performance in this task was the mean time to copy a single word.

In the *word retrieval* task the research participants read lists of words and wrote simple associates to those words as quickly as possible. Each target word was preceded by a common associate and had the first two letters followed by blank lines indicating missing letters. The word pairs were selected from the middle-strength associates provided in the appendix of Nelson and Schreiber (1992). The target words were the same as those used in the word copying task, and thus at least some of the words may have been primed from the previous task. The mean time per item in the task can be hypothesized to reflect the time needed to gain access to familiar material and write several letters of a word.

The *sequential associates* task involved the examiner reading a target word and the research participant producing four successive associates. The examiner recorded the words and also the total time required to generate the four words. A total of ten different target or stimulus words were used, all of which were two-syllable words of high meaningfulness (i.e., ratings 5.27 to 5.98, mean = 5.49, from Clusters 4 and 5 in Toglia & Battig, 1978). Five of the words were high in pleasantness (5.14 to 6.10, mean = 5.76) and five were low in pleasantness (2.38 to 2.87, mean = 2.63) according to the Toglia and Battig (1978) norms. (Association times were very similar, and highly correlated, $r = .83$, for the high- and low-pleasantness words, and thus the data were collapsed across this variable.) The measure of performance was the time to generate four successive associates, which can be hypothesized to reflect internal association time.

The principal criteria used to select other speed tasks were: (a) minimal influence of knowledge; (b) involvement of a variety of response modes, stimuli, and processing requirements; but (c) with little apparent direct relevance to memory. Four of the nonmemory speed tasks were computer-administered reaction time tasks. In all cases the two-alternative choice response was to a pair of stimuli displayed in two vertically positioned boxes in the middle of the screen. In the *letter-letter* task and the *symbol-symbol* task the stimuli were pairs of letters or pairs of symbols, and the decision was based on physical identity, with the "/" key to be pressed if the stimuli were the same and the "Z" key to be pressed if the stimuli were different. In the *letter-symbol* and *symbol-letter* tasks the stimuli were letter-symbol or symbol-letter pairs and the decision was based on associational equivalence according to a code table presented at the top of the screen. If the two stimuli matched according to the code table then the "/" key was to be pressed, and if they did not match then the "Z" key was to be pressed. Each task involved a practice block of 18 trials and two experimental blocks of 45 trials each. The tasks were presented in the order of letter-letter, symbol-symbol, letter-symbol, symbol-letter, and then the same tasks again in the reverse order. The measure of performance was the median reaction time in milliseconds for the two blocks in a given task. Average accuracy was greater than 94% in each task and was not analyzed further.

Four tasks were based on paper-and-pencil procedures. The *letter comparison* and *pattern comparison* tasks were identical to those used in earlier studies (e.g., Salthouse, 1993b, 1994b), and involved the research participant writing the letter "S" or the letter "D" between pairs of letters or pairs of line patterns according to whether they were the same or different. Thirty seconds were allowed for each page, and there were two pages with each task.

The *number matching* and *pattern matching* tasks consisted of a page of rows with a target stimulus on the left and four stimuli to the right, one of which was identical to the target. The stimuli were two-digit numbers in the number matching task, and simple patterns composed of geometric figures in the pattern matching task. In both cases the research participant was to indicate stimuli that matched the target by marking them with a circle or a slash. The measure of performance in all four paper-and-pencil perceptual speed tasks was the number of items answered correctly minus the number of items answered incorrectly in 30 sec. In order to maintain comparability with the other measures, the scores were divided into 30 to yield measures in units of seconds per item.

Two different vocal tasks were used to assess processing speed. One was based on the *Stroop color word* task and involved neutral (Xs), congruent (ink color matches the color word), and incongruent (ink color is incompatible with the color word) stimuli. Each condition consisted of four pages, with 20 items on each page. The conditions were presented in two counterbalanced sequences at neutral, congruent, incongruent, incongruent, congruent, and neutral. The measure of performance was the mean time to name the colors in the four pages of each condition. Research participants were instructed to correct errors when they occurred, but because the correction time contributed to the total naming time, errors were not analyzed separately.

The final speed task required the participants to *count backwards* from a designated number by either 1s, 3s, or 7s. Four trials, each with a different starting number, were presented in each count back condition (i.e., by 1s, 3s, or 7s), and the responses were timed until five successive numbers had been produced. The examiner monitored the accuracy of the responses, correcting errors when they occurred, and recorded the time to produce the five responses. The mean of these times across the four trials in each condition served as the performance measure.

The *vocabulary* test consisted of 10 five-alternative multiple choice synonym vocabulary items and 10 five-alternative multiple choice antonym vocabulary items. The items were selected from published practice tests for the Scholastic Aptitude Test, and were of moderate to high levels of difficulty in samples of college students. Performance on the vocabulary tests consisted of the number of items answered correctly in each section of the test.

RESULTS

Memory Measures

Descriptive statistics for the memory measures are presented in Table 2, and means in each of three age groups expressed in standardized units are illustrated in the upper left panel of Figure 1. The recall scores had a maximum of 10, and the maximum value for the serial memory measure was 8. Because many participants in the reordered (alphabetic) serial memory condition had scores of zero, this measure was not used as an index of memory in later analyses.

The estimated reliability was computed by determining the partial correlation between the two scores for each variable after controlling for age, and then boosting that correlation by the Spearman-Brown formula. This yields estimates of the reliability of the combined score that are independent of the age-related effects on the variable. The reliability of a composite recall measure aggregated across the three presentation rates was .68.

It is apparent in Table 2 that all memory measures have significant negative relations with age. Quadratic age trends were also examined by entering the age-squared term after the age term in a multiple regression equation. Interactions of age with gender, health, and education on the composite recall measure and the three other memory measures were also examined in multiple regression analyses. None of the quadratic age terms were significant, nor were any of the interactions of age with gender, health, or education significant.

Table 2. Descriptive Characteristics of Memory Measures

Variable	Mean	*SD*	Estimated Reliability	Age *r*
Recall – 0.5 sec	3.02	0.99	.52	–.48*
Recall – 1.0 sec	3.56	1.09	.37	–.42*
Recall – 2.0 sec	4.46	1.35	.51	–.43*
Memory search	88.5	10.5	.68	–.26*
Serial memory – original order	5.40	1.80	.74	–.25*
Serial memory – reordered	3.91	2.49	.89	–.25*

$^*p < .01$.

A factor analysis (exploratory with promax rotation) was conducted on the three recall measures at different presentation times and the nonrecall memory measures. Two factors emerged in this analysis, with the first factor having high loadings on the recall measures and the second factor having high loadings on the nonrecall (i.e., memory search and serial memory accuracy) measures. The correlation between factors was .33, and the age correlations were –.53 for the first factor and –.29 for the second factor. The recall measures with the three different presentation times loaded on the same factor and had similar correlations with age, and thus they appear to reflect similar processes despite different absolute levels of performance. Many of the later analyses used the composite recall measure (average across all three rates) to assess memory because it is one of the simplest measures, is most comparable to other measures of memory, and had the highest reliability of the recall measures.

Speed Measures

Descriptive statistics for the speed measures are contained in Table 3, and mean standardized scores in each of three age groups are illustrated in the lower left, upper right, and lower right panels of Figure 1. (Because many participants were unable to perform the reordered serial memory task and the counting backwards by 7 task correctly, the measures from these tasks were deleted from subsequent analyses.) Estimated reliabilities, computed as described above, were generally high for the speed measures, with many of them above .9. Also reported in Table 3 are correlations of the speed measures with age and with the composite recall memory measure. All correlations were significantly different from 0 except for the correlation of age with the count back 3 measure. The quadratic age trends (age-squared term) were significant with the pattern comparison (increment in R^2 = .051), letter comparison (increment in R^2 = .063), number matching (increment in R^2 = .028), pattern matching (increment in R^2 = .030), color neutral (increment in R^2 = .056), color congruent (increment in R^2 = .069), and color incongruent (increment in R^2 = .059) measures. In all cases, the significant quadratic effect occurred because the age trend

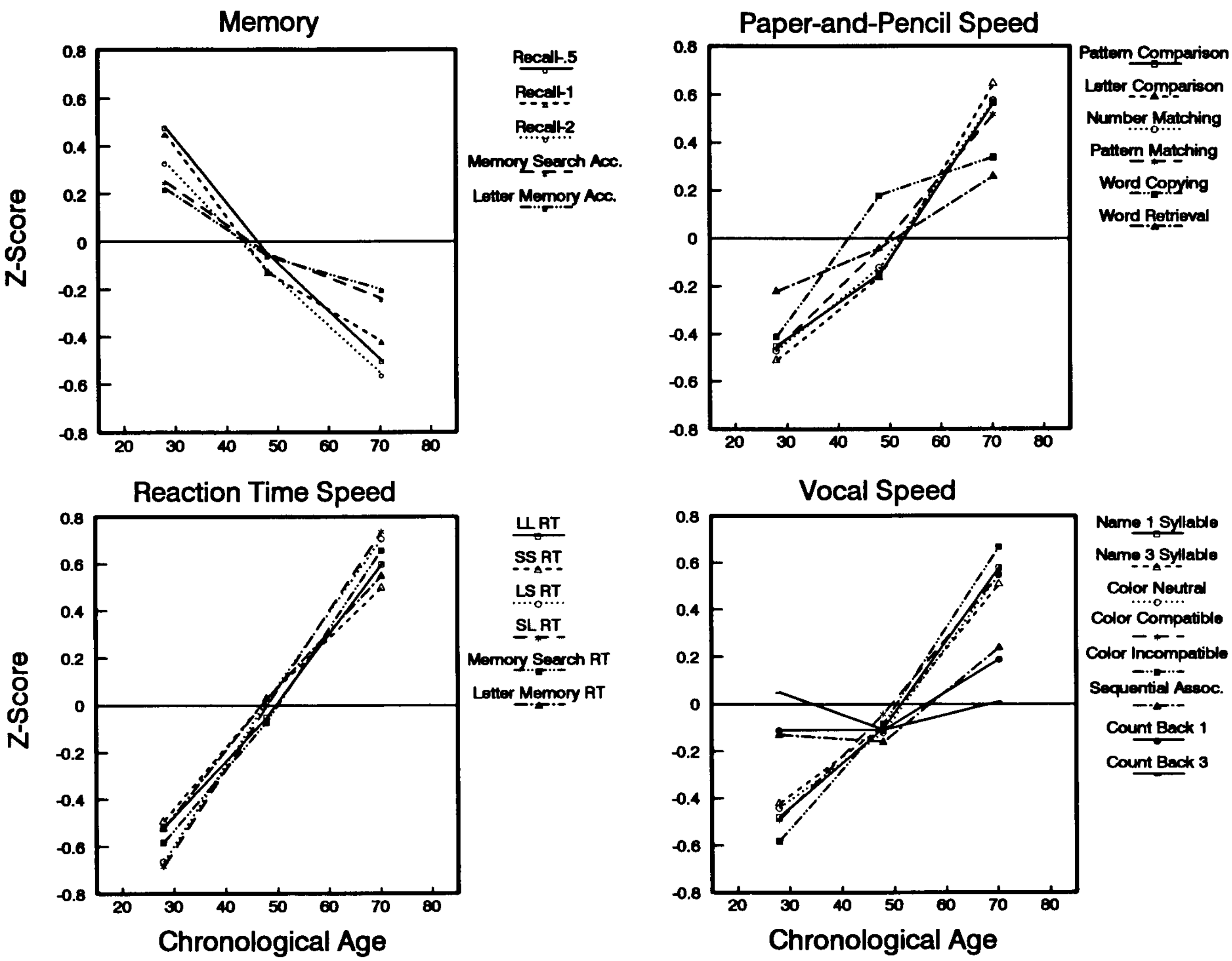

Figure 1. Mean levels of performance, expressed in standard deviation units, across three age groups.

accelerated in the oldest ages. Age × health interactions, in the direction of larger age relations among individuals with low levels of self-reported health, were significant for the pattern comparison, letter comparison, memory search reaction time, serial memory original time, and the count backwards by 1s and by 3s measures. No interactions of age × gender nor age × education were significant on any of the speed measures.

Inspection of Table 3 reveals that the magnitude of the relation to memory was similar for most of the speed measures. It is noteworthy that the relations to the composite memory measure were not appreciably higher for measures hypothesized to reflect processes that might be particularly relevant to memory (i.e., word retrieval, memory search, serial memory, sequential associates) than for other speed measures.

Multiple regression equations were used to compute the variance each variable shared with both age and recall memory. First the R^2 for age alone was computed, and then the increment in R^2 for age after control of the speed variable. Next, the latter value was subtracted from the former, and divided by the former. When the product of these computations is multiplied by 100 the result corresponds to the percentage of the age-related variance (i.e., R^2) in the memory variable that is shared with the speed variable. As an example, the age-related variance in the composite memory measure in the total sample was .289, and the increment in R^2 associated with age after control of the pattern comparison measure was .084. Because (.289 − .084)/.289 = .709, and .709 multiplied by 100 = 70.9%, it can be inferred that the age-related variance in the composite memory measure would be reduced by 70.9% if the variance in the pattern comparison measure were held constant.

Values in the last column of Table 3 indicate that most of the speed variables shared at least moderate amounts of variance with the age and memory variables. Once again, however, it is important to note that the values are not especially high for the measures assumed to reflect processes closely related to memory functioning. In fact, the measures of word retrieval time and sequential associates time had relatively low estimates of shared variance with age and memory.

Table 3. Descriptive Characteristics for Speed Measures

Variable	Mean	*SD*	Estimated Reliability	Correlations Age	Correlations Memory	% Variance Shared With Age and Memory
Pattern Comparison	2.24	0.95	.77	.54*	−.55*	70.9
Letter Comparison	3.91	1.95	.56	.62*	−.59*	83.0
Number Matching	1.29	0.39	.89	.55*	−.48*	62.6
Pattern Matching	2.48	1.33	.81	.50*	−.51 *	62.6
Word Copying	2.22	0.58	.94	.39*	−.56*	58.1
Word Retrieval	3.10	1.39	.81	.25*	−.51*	38.4
Letter–Letter RT	0.87	0.43	.75	.57*	−.49*	65.7
Symbol–Symbol RT	0.98	0.57	.82	.53*	−.51*	65.1
Letter–Symbol RT	2.01	0.64	.88	.69*	−.58*	87.5
Symbol–Letter RT	2.09	0.70	.94	.72*	−.57*	88.2
Memory Search RT	1.76	0.65	.91	.62*	−.45*	61.2
Serial Memory Orig. RT	1.71	0.93	.93	.56*	−.54*	72.3
Name – One Syllable	3.71	0.94	.77	.53*	−.40*	49.5
Name – Three Syllables	5.20	1.25	.87	.46*	−.39*	42.9
Color – Neutral	11.67	3.99	.93	.51*	−.40*	47.4
Color – Congruent	10.47	4.09	.91	.54*	−.34*	38.8
Color – Incongruent	21.16	7.51	.93	.65*	−.52*	75.8
Sequential Associates	17.68	9.85	.96	.21*	−.30*	18.3
Count Back – 1	5.59	2.19	.68	.18*	−.36*	19.7
Count Back – 3	16.47	9.74	.85	.06	−.31*	6.9

$^*p < .01$.

General — Specific Analyses

Structural equation analyses were the primary method used to derive estimates of the general and specific age-related influences on the observed speed measures. An initial exploratory factor analysis on the 20 speed measures listed in Table 3 revealed four factors with eigen values greater than one. However, the pattern of loadings of the variables on the factors was not easily interpretable, and the correlations among factors were moderately high (i.e., .37 to .58). A confirmatory factor analysis was next conducted with factors corresponding to paper-and-pencil (i.e., the first six variables in Table 3), reaction time (i.e., the second six variables in Table 3), and vocal (i.e., the last eight variables in Table 3) tasks. Although this model provided a moderate fit to the data (i.e., χ^2 [N = 172, df = 141) = 392.57; NNFI = .90; CFI = .92), the correlations between the factors were extremely high (i.e., .77 between paper-and-pencil and reaction time, .79 between reaction time and vocal, and .97 between paper-and-pencil and vocal), suggesting that any method-based factors that might exist were not very distinct.

On the basis of these preliminary analyses, the initial model consisted of a single general speed factor and two memory factors (corresponding to the recall and nonrecall tasks). This measurement model provided a moderate fit to the data after allowing correlated residuals between variables sharing the same assessment (i.e., χ^2 [N = 172, df = 264] = 723.07; NNFI = .85; CFI = .87). The first structural model added age to the analysis, with a direct path to the speed factor and indirect paths, through speed, to the memory factors. The fit of this model was adequate (i.e., χ^2 [N = 172, df = 289] = 800.46; NNFI = .85; CFI = .86). Direct paths from age to all the observed speed variables were then examined, and the paths with coefficients different from zero by two standard errors retained. Six variables had significant coefficients, and the fit of the resulting model, portrayed in Figure 2, was somewhat better (i.e., χ^2 [N = 172, df = 283] = 746.27; NNFI = .86; CFI = .88). Attempts to improve the fit of the model by adding direct paths from age to the memory factors, and to the observed memory variables, did not result in significant improvements in fit, or in any path coefficients that differed from zero by more than two standard errors. Because all relations from age were examined, it can be concluded that although the fit of the model was not particularly impressive, it is unlikely that age has more relations to the variables than those already represented in the model.

The first point to note about Figure 2 is that most of the age-related influences on the individual speed variables can be modeled as being mediated through a general or common speed factor. That is, the direct paths from age to the speed variables are both few in number and small in magnitude. Estimates of the general (mediated) age-related influences on the variables can be obtained from the product of the path coefficients from age to the general speed factor and from the general speed factor to the variable. These estimates, as well as the estimates of the specific (direct) age-related effects, and the total age-related effects in the form of the age correlation, are listed in Table 4.

According to path analysis logic, the correlation between age and the variable can be partitioned into direct (specific) and indirect (general) components. In other words, if these are the only factors operating in this situation, then the sum of the general and specific age-related effects for a given variable should equal the total age-related effects on that variable. The correspondences between the correlations and the sum of the general and specific coefficients in Table 4 are

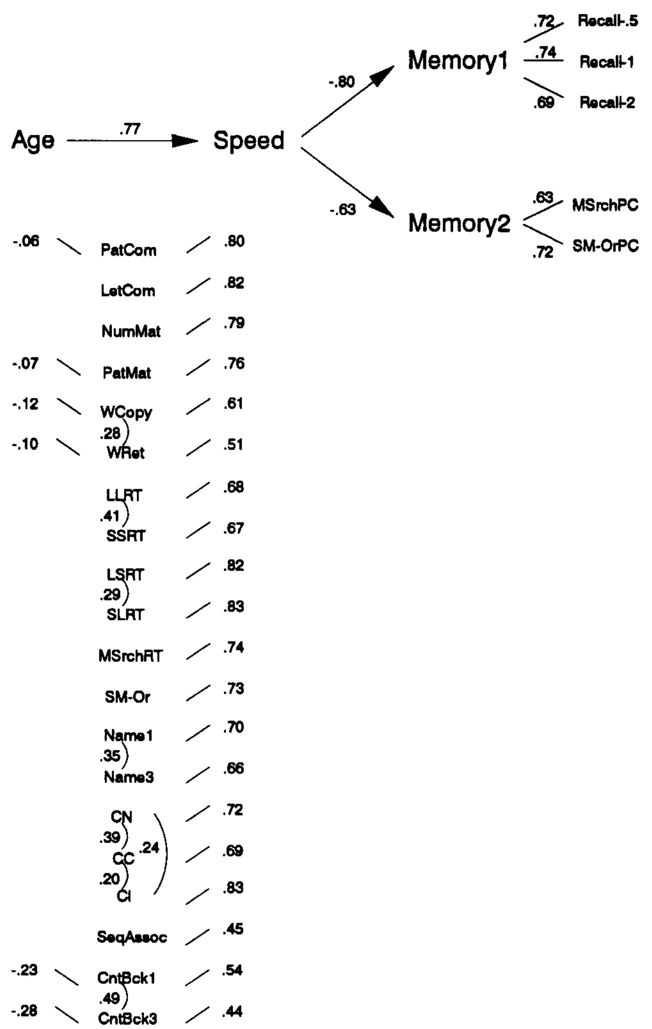

Figure 2. Results of structural equation model analysis with speed and memory measures. The memory variables are listed in Table 2 and the speed variables in Table 3. Lines to the speed variables represent paths from Age or from the General Speed factor, and lines to the memory variables represent paths from the Memory factors. All coefficients are standardized.

not exact, but they are close enough to suggest that the general and specific estimates from this analysis may be reasonable approximations to the true values.

A similar analysis was carried out when the first (unrotated) principal component from a principal components analysis was used as the estimate of the general speed factor [see Jensen (1980) and Ree & Earles (1991) for the rationale underlying this method of estimating a general factor]. The standardized regression coefficients in a simultaneous regression equation with the first principal component and age as predictors of the speed variable were then used to derive estimates of the general and specific age-related influences. That is, the specific effect was the regression coefficient from age (when it was significantly, at $p < .05$, different from zero), and the general effect was the product of the regression coefficient from the first principal component and the correlation coefficient (i.e., .69) between age and the first principal component. These estimates derived from the principal components analysis are listed in the fifth and sixth columns of Table 4.

Although the values of the estimates differ according to how the general speed factor is derived, it is clear that for most of the variables a very large proportion of the total age-related variance was mediated through the general speed factor. The general speed effect was larger than the observed age effect on several measures (e.g., word retrieval, counting backwards by 1s, and counting backwards by 3s), suggesting that other factors may have been operating to counteract the general influence. Factors operating to increase the size of the age effects may have been operating when the estimates of the specific effects are the same sign as those for the general effects (e.g., the symbol-letter RT measure in the principal components analysis).

The inference that a considerable amount of the age-related variance on the speed measures was shared is also confirmed by analyses of quasi-partial correlation coefficients (Salthouse, 1994a). Unlike traditional correlations, which reflect the proportion of the total variance that is shared between two variables, quasi-partial correlations reflect the proportion of age-related variance in two variables that is shared. The median quasi-partial correlation among the 19 speed variables (excluding the count back by 3s measure which had very little age-related variance that could be partitioned) was .79, with a range from .45 to .99. It can therefore be inferred that, on the average, approximately 62% (i.e., $.79^2$) of the age-related variance in pairs of speed variables was shared.

Derived Measures

In addition to the directly observed speed measures, a number of derived measures can be created to represent the duration of potentially more specific processes. These derived measures are described in Table 5 along with summary statistics for the measures. Each measure is obtained either from subtraction or from a linear regression equation, and they can be interpreted as representing the time needed to: (a) search the code table and substitute items; (b) search and retrieve an item from memory; (c) reorder items in memory; (d) articulate (and possibly rehearse) verbal material; (e) suppress incongruent or incompatible information; (f) benefit from congruent or compatible information; or (g) carry out easy and difficult mental manipulations.

Many of the derived measures have moderate reliability, and some also have moderate correlations with the composite memory measure. However, the correlations are not higher for the measures presumed to be most relevant for memory functioning than for the other measures. To illustrate, the two derived measures for which the correlations with the composite memory variable are highest are substitution and interference, which are not obviously related to memory. Furthermore, the intercept of the memory search function has higher relations to age and to the composite memory variable than does the slope parameter, despite a general assumption that the intercept reflects primarily perceptual and motor processes whereas the slope reflects processes associated with search through information in memory.

The independence of the age relations in the derived measures was examined with two analytical procedures. In

Table 4. Estimates of General and Specific Age-Related Influences on Speed Measures

Variable	Total Age Effect Correlation	*SEM* Estimates		PCA Estimates	
		General	Specific	General	Specific
Pattern Comparison	.54	.62	−.06	.57	0
Letter Comparison	.62	.63	0	.51	0
Number Matching	.55	.61	0	.59	0
Pattern Matching	.50	.59	−.07	.55	0
Word Copying	.39	.47	−.12	.49	0
Word Retrieval	.25	.39	−.10	.50	−.24
Letter–Letter RT	.57	.52	0	.40	.17
Symbol–Symbol RT	.53	.52	0	.45	0
Letter–Symbol RT	.69	.63	0	.46	.23
Symbol–Letter RT	.72	.64	0	.42	.29
Memory Search RT	.62	.57	0	.40	.22
Serial Memory Orig.	.56	.56	0	.46	0
Name – One Syllable	.53	.54	0	.52	0
Name – Three Syllables	.46	.51	0	.53	0
Color – Neutral	.51	.55	0	.58	0
Color – Congruent	.54	.52	0	.50	0
Color – Incongruent	.65	.64	0	.55	0
Sequential Associates	.21	.35	0	.48	−.26
Count Back – 1	.18	.42	−.23	.60	−.42
Count Back – 3	.06	.34	−.28	.58	−.52

Note: Specific effects identified when $p < .05$.

Table 5. Descriptive Characteristics of Derived Speed Measures

Variable	Mean	*SD*	Estimated Reliability	Correlations		% Variance Shared With Age and Memory
				Age	Memory	
Substitution Time (Letter–Symbol + Symbol–Letter RT) − (Letter–Letter RT + Symbol–Symbol RT)	3.17	1.04	.90	.64*	−.50*	72.0
Memory Search Slope (Slope of regression of memory search RT on number of memory set items)	0.06	0.12	.58	.02	.02	0
Memory Search Intercept (Intercept of regression of memory search RT on number of memory set items)	1.60	0.72	.82	.52*	−.39*	47.7
Memory Reorganization Time (n = 148) (Time to recall letters in alphabetic order minus time to recall letters in original order)	1.36	1.08	.68	.23*	−.34*	18.0
Articulation Time (Time to read 3-syllable words minus time to read 1-syllable words)	1.49	0.73	.39	.10	−.14	4.5
Stroop Interference Time (Time to name incongruent colors minus time to name neutral colors)	9.50	4.71	.81	.60*	−.49*	67.8
Stroop Facilitation Time (Time to name neutral colors minus time to name congruent colors)	1.20	1.89	.60	−.09	−.10	0
Easy Count Back (Time to count backwards by 3 minus time to count backwards by 1)	10.88	8.29	.79	.03	−.27*	2.8
Difficult Count Back (n = 161) (Time to count backwards by 7 minus time to count backwards by 1)	23.53	17.63	.92	−.01	−.17	0

*$p < .01$.