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The Nature of the Influence of Speed on Adult Age Differences in Cognition

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Two studies were conducted to determine the relations among age, motor speed, perceptual speed, and 3 measures of cognitive performance: study time, decision time, and decision accuracy. Each study involved over 240 adults between 18 and over 80 years of age who all performed a battery of tests, including computer-administered tests of memory, reasoning, and spatial ability. The results indicated that (a) increased age was associated with lower accuracy as well as with longer study time and decision time and (b) some of the relations between age and decision accuracy and between age and decision time appear to be mediated by a slower rate of executing cognitive operations.

A convincing argument that a construct is involved in the mediation of the relations between age and cognition could be based on the following combination of evidence: (a) demonstration of a negative relation between age and measures of the hypothesized mediator, (b) demonstration of a positive relation between measures of the mediator and measures of cognition, and (c) substantial attenuation of the relations between age and cognition after measures of the mediator are statistically controlled. Several theoretical constructs have been proposed as potential mediators of the relations between age and cognition, with reduced attention (e.g., Stankov, 1988) and failure of inhibition (e.g., Hasher & Zacks, 1988) among the most prominent at the current time. Most of the research concerning these particular constructs has been focused on establishing relations between age and measures of the hypothesized mediators. The linkage between these constructs and cognitive functioning has seldom been directly investigated, and little or no evidence is available concerning the magnitude of the attenuation of the age differences in cognition when the variance in the measures of the hypothesized mediator is held constant.

Two theoretical constructs in which each type of evidence is available are working memory capacity and speed of processing (e.g., Salthouse, 1991, 1992a, 1992b, 1992e; Salthouse & Babcock, 1991). However, there is also evidence that the attenuation of the age–cognition relations is greater after measures of processing speed are controlled than after measures of working memory are controlled, and that the relations between age and working memory are substantially attenuated when processing speed measures are controlled (Salthouse, 1991, 1992a, 1992e; Salthouse & Babcock, 1991). Taken together, these results suggest that processing speed may be more fundamental than working memory as a mediator of age–cognition relations.

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Considerable evidence now exists indicating that a large proportion of the age-related variance in many different cognitive variables is shared with a measure of perceptual speed. Among the most pertinent results are the findings that the age-related differences in various measures of cognitive functioning are greatly reduced when statistical control procedures are used to adjust for differences in perceptual speed. As an illustration of this phenomenon, Table 1 in Salthouse (1993b) contains 44 comparisons across a wide range of cognitive variables. Age was associated with a mean of 16.2% of the total variance in the variables, but after the variance associated with measures of perceptual speed was held constant, age was associated with only 3.6% of the variance in the cognitive variables.

One interpretation of this pattern of results is based on the assumption that the well-documented finding that increased age is associated with lower scores on many measures of speeded performance reflects an age-related reduction in the speed with which many cognitive operations can be executed. All cognitive processes are not necessarily affected by this age-related slowing, and there may be more than one distinct speed factor operating. However, it is assumed that when the required operations are very simple, as in many perceptual speed tasks, much of the variation in performance is associated with the speed with which many elementary cognitive operations can be executed. It is also hypothesized that this slower processing impairs higher order processes such as integration and abstraction because less relevant information is simultaneously available when needed. This argument was illustrated abstractly in a computer simulation described in Salthouse (1988), and the ideas have been elaborated in Salthouse (1992a) and Salthouse and Babcock (1991). A basic premise is that if decay rate remains constant across age but there is an age-related slowing of the rate of activation, then some of the early information will no longer be available by the time that later information has been processed, and that this will be true to a greater extent in older adults than in young adults. A fundamental implication of this interpretation is that slower processing leads to an impairment in the quality of decisions and not simply in a longer time to reach and communicate decisions.

The present project had three major goals. The first goal was to determine whether there is comparable speed mediation of the age relations on cognitive measures obtained without time limits. Most of the previous studies have used timed paper-and-pencil tests, and thus it is possible that the attenuation of the age relations after control of measures of perceptual speed might be smaller with power tests in which there are no external time limits. There is some evidence that this is not the case, but the relevant data are based on only a few small-scale studies (e.g., Salthouse, 1993a).

The second major goal of the project was to investigate the type of speed mediation involved in the relations between age and cognition. One theoretically interesting distinction is between motor speed and perceptual speed. Motor speed tasks typically have minimal cognitive requirements and can be postulated to primarily reflect the speed of sensory and motor processes. In contrast, perceptual speed tasks involve various types of cognitive operations, such as comparison, substitution, or transformation, in addition to sensory and motor processes. Salthouse (1993b; also see Salthouse, 1992b) recently reported that the attenuation of the age–cognition relations was larger when perceptual speed measures were controlled than when motor speed measures were controlled. One purpose of this project was to attempt to replicate this pattern with the same paper-and-pencil speed measures used earlier and to extend it to new speed measures derived from computer-administered tasks.

The degree of cognitive involvement in computer-administered speed tasks was varied by altering the number of cognitive operations required to perform the task. That is, the number of digit-symbol pairs was manipulated in a digit-symbol substitution test, and the number of memory set items was manipulated in a memory search test. Cognitive involvement was assumed to be minimal in the simplest versions of the task but progressively greater in tasks requiring multiple comparison, association, memory search, or substitution operations. The degree of cognitive involvement was also postulated to be minimal in the intercept parameter of the regression functions relating number of operations to reaction time, but substantial in the slope parameter of those functions because the latter can be presumed to reflect the duration of cognitive operations such as association or memory search.

A third major goal of the project was to examine the relation among age, various measures of speed, and three measures of performance derived from computer-administered cognitive tests, namely, study time, decision time, and decision accuracy. There are several possible ways in which these variables could be interrelated, and each has different implications for the manner in which a slower speed of processing mediates the relations between age and measures of cognitive functioning. For example, increased age might be associated with longer study or solution time and with longer decision time, but not with lower decision accuracy. A pattern of this type would suggest that despite an age-related slowing of certain types of processing, adults of all ages may be equally able to achieve the same level of decision accuracy when allowed sufficient time. Conversely, negative relations might exist between age and decision accuracy independent of any relations between age and study time or decision time. An outcome of this type would obviously be consistent with the theoretical perspective outlined earlier because age-related effects would be evident in the quality of the decisions in addition to effects on the time to reach or communicate decisions.

Relations might also exist among the study time, decision time, and decision accuracy variables. For example, a speed–accuracy trade-off might be evident in the form of a positive relation (higher accuracy associated with longer time) between decision accuracy and either study time, decision time, or both. Alternatively, the relation could be negative, indicating that people who are slow are also not very accurate. Finally, it is also of interest to determine the nature of the relations between various speed measures and both study time and decision time. If a common speed factor influences every time measure, then strong relations might be expected among all measures.

Because the pattern of relations among the various measures could vary across tests, it is important that analyses of the type just described be conducted with several different cognitive tests. Moreover, it is always desirable to examine the reliability of the major findings by attempting to replicate them in an independent sample of subjects. This project therefore consisted of two separate studies, both containing paper-and-pencil and computer-administered speed tests, and three computer-administered cognitive tests. Within each study, the computer-administered cognitive tests, which were assumed to require memory, reasoning, or spatial ability, were designed to yield separate measures of study time, decision time, and decision accuracy. Three analytical methods were used: hierarchical multiple regression to determine the amount of age-related variance before and after control of the variance in different speed measures; commonality analysis to partition the age-related variance into portions unique to age and shared with motor speed, perceptual speed, or both; and path analysis to examine the interrelations among the age, speed, study time, decision time, and decision accuracy variables.

Study 1

Method

Subjects. Table 1 summarizes the characteristics of the 246 adults between 18 and 84 years of age who participated in Study 1. (Adults in their 70s and 80s are reported together because of the small number of individuals in each of these age decades.) The subjects were recruited from a variety of sources, such as personal acquaintances, clubs, organizations, or neighborhood newspapers, and each was paid for participating in a single session lasting approximately 2 to 3 hr. None of the subjects was currently attending school on a full-time basis.

Two background questions concerned the subject's education: "How many years of formal education have you completed?" and "Which of five categories (<12, 12, 13–15, 16, >16) best describes the highest grade (or degree) you have completed?" The correlation between responses to these items was .93. The entry in Table 1 represents the results from the question of how many years of education had been completed. This variable had a correlation with age of −.20 ($p < .01$).

Six background questions were designed to assess health. One question asked for an evaluation of one's health on a scale ranging from 1 = *excellent* to 5 = *poor.* Three additional questions also used a 5-point scale and asked for ratings of overall health, satisfaction with health, and degree of limitations of daily activities owing to health status. Correlations among these measures were moderate to high (.47 to .78). Two yes/no questions asked whether the individual had had surgery for cardiovascular problems or was taking medication for high blood pressure.

Table 1
Demographic Characteristics of Research Participants

Decade	*n*	Age (years)	% female	Eduation (years) *M*	Eduation (years) *SD*	Health[a] *M*	Health[a] *SD*
			Study 1				
20s	48	23.4	46	14.7	2.1	1.8	0.7
30s	43	33.9	58	15.5	1.6	2.2	0.9
40s	48	44.2	69	14.8	2.1	2.0	0.9
50s	40	54.7	72	14.1	2.2	2.6	1.2
60s	44	64.6	61	14.0	2.6	2.0	1.0
70s+	23	75.0	65	13.1	2.2	2.4	0.8
Total	246	46.6	61	14.5	2.2	2.1	1.0
			Study 2				
20s	35	25.1	46	15.0	1.7	1.8	0.7
30s	58	34.0	59	15.8	2.3	1.8	0.8
40s	50	44.6	66	15.6	2.3	2.0	0.9
50s	33	54.2	73	14.9	2.2	2.0	0.8
60s	46	64.5	52	15.7	2.5	1.9	0.9
70s+	36	75.8	69	14.3	2.4	2.0	1.0
Total	258	48.7	60	15.3	2.3	1.9	0.8

[a] From 1 = *excellent* and 5 = *poor.*

Responses to these items had very low correlations with the other items (.04 to .27). The health variable in Table 1 refers to the first overall health rating, which had a correlation with age of .13 ($p > .01$).

Procedure. Subjects were tested in groups of 1 to 4, and for the computer-administered tests a separate personal computer was provided for each subject. All subjects performed the tests in the following order: Boxes, Pattern Comparison, Number Series Completion, Name Number, Cube Assembly, Letter Comparison, Digit Copying, Digit Symbol, Paper Folding, Matrix Reasoning, and Associative Memory. The abilities postulated to be assessed by the tests were motor speed (Boxes and Digit Copying), perceptual speed (Pattern Comparison, Letter Comparison, and Digit Symbol), reasoning (Number Series Completion and Matrix Reasoning), spatial visualization (Cube Assembly and Paper Folding), and memory (Name Number and Associative Memory).

The first seven tests were in a paper-and-pencil format. The Boxes test was from Salthouse (1993b). The form for this test consisted of 10 rows of 10 three-sided squares with the top, bottom, left, or right side open. The task for the subject was to draw a line across the open side to make a closed box, and the measure of performance was the number of boxes drawn within 30 s.

The Digit Copy test was also from Salthouse (1993b). The form in this test consisted of 10 rows of 10 pairs of boxes with a digit in the top box and nothing in the bottom box. The task was to copy the digit from the top box in the box immediately below it, and the measure of performance was the number of digits copied within 30 s.

The Letter Comparison test was from Salthouse (1991, 1993b) and Salthouse and Babcock (1991), and it required the subject to inspect pairs of three, six, or nine letters and then write an S if the two pairs are the same and a D if they are different. The test form consisted of a single column of 21 pairs of letters with a blank line between them. The measures of performance were the numbers of correct and incorrect responses produced within 30 s.

The Pattern Comparison test was also from Salthouse (1991, 1993b) and Salthouse and Babcock (1991). Subjects in this test were asked to inspect pairs of line patterns composed of three, six, or nine line segments and then to write an S if the pair of patterns is the same and a D if they are different. The test form consisted of two columns of 15 pattern pairs, each with a blank line between the two members of the pair. The number of correct responses and the number of incorrect responses produced within 30 s served as the measures of performance in this test.

Three of the paper-and-pencil tests were administered for 2 min each. The Number Series test was similar to the Number Series Completion test described by Salthouse and Prill (1987). The test form consisted of 20 problems, each involving a series of five elements. First-order problems were based on a simple continuation (e.g., 2-4-6-8-10-??), second-order problems were based on a relation among the differences between elements rather than among the elements themselves (e.g., 2-4-7-11-16-??), and alternating-order problems consisted of two interleaved relations (e.g., 2-13-4-11-6-??). Each successive set of 5 problems had 1 first-order problem, 2 second-order problems, and 2 problems with alternating relations. Subjects answered the problems by writing the best continuation of the series on the test form.

The Cube Assembly test was originally based on a task described by Shepard and Feng (1972), and it has been used previously in Salthouse (1991, 1992d). Problems in the test consist of a pattern of six connected squares representing an unfolded cube. One of the squares is marked as the base of the cube, and two squares contain arrows pointing to one side of the square. The task is to decide whether the arrows would be pointing at one another if the squares were assembled into a cube. The test contains 24 problems, with an equal number of problems in which one, two, or three folds were required to assemble the cube. One problem of each type was presented before another of the same type. Decisions were communicated by placing a check in a column labeled YES (indicating the arrows would touch) or in a column labeled NO (indicating they would not touch), located adjacent to the problem on the test form.

The Name–Number test consisted of the presentation of 10 first names (5 male and 5 female), each paired with a number between 10 and 99. The pairs were presented together for 1 min, and then the subject was presented with the list of names in a reordered sequence and was allowed 1 min to write the numbers associated with the names. Performance was assessed in terms of the numbers of correct and incorrect name–number pairs.

All computer-administered tests were preceded by written instructions and several practice trials, and all except the first test had a primary emphasis on accuracy rather than speed. The Digit Symbol test was based on the test described in Salthouse (1992c). Nine, 6, 3, or 0 digit-symbol pairs were presented in a code table in the top of the computer screen, and a pair of items, either a digit and a symbol or two digits, appeared in the middle of the screen. The subjects were instructed to respond with the rightmost slash (/) key on the bottom row of the keyboard if the items were physically identical or matched according to the code table, and with the leftmost (Z) key on the bottom row of the keyboard if the items did not match. One practice block of 18 trials was presented with nine digits and nine symbols, followed by eight experimental blocks of 90 trials each. The number of symbols across the eight blocks were 9, 6, 3, 0, 0, 3, 6, and 9, respectively. In conditions with either 3 or 6 symbols, one of the blocks had the symbols paired with the first *n* digits (where *n* is 3 or 6), and the other block had the symbols paired with the last *n* digits. The remaining digits had the symbol in the code table replaced with identical digits (e.g., 2 with 2, 4 with 4, and so on). Trial selection was based on all nine digits regardless of condition, and thus approximately one third and two thirds of the trials in the conditions with 6 and 3 symbols, respectively, involved comparisons of pairs of digits rather than a digit paired with a symbol. One half of the trials in each block required a positive response (because the members of the pair matched), and one half required a negative response (because the members of the pair did not match). Subjects were instructed to respond as rapidly and accurately as possible.

The computer-administered Paper Folding test was based on the test of the same name described in several earlier articles (i.e., Salthouse, Babcock, Mitchell, Palmon, & Skovronek, 1990; Salthouse, Babcock, Skovronek, Mitchell, & Palmon, 1990; Salthouse, Mitchell, Skovronek, & Babcock, 1989). Trials in this task were initiated by pressing the ENTER key on the keyboard. This led to a dynamic display of the first fold, and subsequent folds or the location of the hole punch were displayed after each successive press of the ENTER key. After the display of the punch location, another press of the ENTER key resulted in a display of a pattern of holes accompanied by the words NO on the lower left of the screen and YES on the lower right of the screen. Decisions were communicated by pressing the Z or slash key, respectively. Three trial types were distinguished on the basis of the number of folds (one, two, or three) presented before the display of a hole punch. Subjects could inspect each display of the product of a fold or the hole punch as long as desired and could take as long as necessary to make a decision. The total time inspecting the folds and examining the position of the hole punch served as the measure of study time, and the time to respond to the pattern of holes served as the decision time. A practice block of 3 trials contained a detailed explanation of the task, and it could be repeated as often as desired. This was followed by two blocks of 24 trials each, composed of 8 trials with each number of folds arranged in a random order.

The Matrix Reasoning test was based on the test described in Salthouse (1993a), which in turn was based on the Raven Progressive Matrices test. Problems consisted of a 3 × 3 matrix with geometric patterns in each of eight cells and a set of eight patterns representing possible completions of the missing cell in the matrix. The matrix and the completion alternatives were presented successively in separate screens on the computer. Study time was measured as the time to inspect the matrix, and decision time was measured as the time from the presentation of the answer alternatives to the registration of the numeric response indicating which of the answer alternatives was selected. Subjects could inspect the matrix and the set of alternatives as long as desired but could not return to the matrix after advancing to the display of the answer alternatives.

The practice block of 3 trials was repeatable, and it was followed by two experimental blocks of 18 trials each. Three trial types were distinguished by the number of relevant relations among the elements in the matrix (cf. Salthouse, 1993a). Six trials in each experimental block contained each number of relations, and they were presented in a random order.

The Associative Memory test was a continuous paired-associate task designed to measure the ability to remember associations between words and digits. The test involved the presentations of either a word paired with a digit (from the set of one, two, or three) or a single word. When a word and a digit were presented, the subject was allowed to inspect the pair for as long as desired. When a word was presented alone, the subject was to type the digit that had been previously presented with that word. The time devoted to the initial inspection of the word–digit pair was used as the measure of study time, and the time to enter a digit in response to the test word was used as the measure of decision time.

A practice list of 6 pairs was presented, followed by an experimental list of 90 pairs with 24 tests (8 each at lags of zero, two, or four intervening items). The stimulus words were nouns between four and eight letters in length with Kucera-Francis frequencies of 10 or greater with above average ratings in concreteness and imagery, from the Toronto Word Pool (Friendly, Franklin, Hoffman, & Rubin, 1982).

Results and Discussion

Because of the many statistical comparisons and the relatively large sample size, an alpha level of .01 was adopted for all statistical significance tests reported in this article.

Table 2
Summary Statistics for Primary Dependent Variables, Study 1

Variable	*M*	*SD*	Est. Rel.	R^2 Linear age	R^2 Quadratic age
Boxes	50.5	13.1	.78[a]	.290*	.006
Digit Copy	51.5	11.2	.84[a]	.281*	.030*
Letter Comparison	9.4	3.4	.38[a]	.251*	.018
Pattern Comparison	15.4	3.9	.52[a]	.374*	.001
Digit Symbol-0 (s)	0.76	0.23	.94[b]	.262*	.046*
Digit Symbol-9 (s)	1.50	0.40	.95[b]	.374*	.021*
Intercept (s)	1.05	0.30	.86[b]	.284*	.027*
Slope (s)	0.05	0.03	.44[b]	.115*	.001
Correct − incorrect					
Number Series	2.49	4.23	.67[a]	.118*	.004
Cube Assembly	4.02	4.70	.70[a]	.091*	.012
Name Number	1.15	3.81	.46[a]	.070*	.006
% correct					
Paper Folding	69.7	11.9	.72[c]	.215*	.007
Matrix Reasoning	57.5	21.9	.88[c]	.149*	.009
Associative Memory	67.5	12.2	.45[c]	.071*	.002
Decision time (in s)					
Paper Folding	2.41	0.82	.89[c]	.336*	.005
Matrix Reasoning	6.00	3.94	.93[c]	.241*	.009
Associative Memory	2.88	1.46	.93[c]	.231*	.050*
Study time (in s)					
Paper Folding	6.24	3.55	.93[c]	.057*	.001
Matrix Reasoning	26.89	14.42	.90[c]	.067*	.017
Associative Memory	1.76	1.17	.96[c]	.023	.007

Note. Est. Rel. = estimated reliabilities.
[a] Alternate-forms correlation from a sample of 212 college students.
[b] Correlation between scores from first and second administrations boosted by the Spearman-Brown formula. [c] Computed from correlations across three levels of complexity with formula in Kenney (1979, p. 132): Reliability = n(average r)/[1 + (n − 1)(average r)].
* $p < .01$.

Table 2 contains the means, standard deviations, estimated reliabilities, and R^2 values for the linear and quadratic age relations for the primary dependent variables. Quadratic trends were evaluated by an age-squared term entered after the linear age term in a multiple regression equation and after both the age and the age-squared variables had been centered to means of zero to reduce potential multicollinearity problems (Cohen & Cohen, 1983). Because the quadratic trends were always small in relation to the linear trends, they were ignored in subsequent analyses.

Most reliabilities were in the respectable range, although those for the Name Number measure and for the measure of decision accuracy in the Associative Memory test were much lower than desirable. In both cases it appears that the tasks may have been too difficult for many of the research participants because the average levels of performance were quite low. Reliability estimates for the Letter Comparison and Pattern Comparison variables were low in the pilot sample of college students, perhaps because of the restricted age range in this group. However, these variables had correlations with other variables in this sample that were higher than the estimated reliability, and thus the reliability in the present sample was likely greater than that derived from the student sample. As an example, the correlations of the Letter Comparison and Pattern Comparison variables with age were −.50 and −.61, respectively, and the correlation between the two variables was .55.

Paper-and-pencil tests. Performance in the paper-and-pencil tests was initially analyzed in terms of the number of correct responses, the number of incorrect responses, and the number of correct responses minus the number of incorrect responses. The age relations were weak with the measure of number of incorrect responses, as the age correlations were −.03 for Pattern Comparison, .09 for Letter Comparison, .13 for Number Series, .18 for Cube Assembly, and .06 for Name Number Association. Only the correlation for Cube Assembly was significantly different from zero. The age relations were similar for the measures of number correct and number correct minus number incorrect, and the correlations between the two measures were generally high: Pattern Comparison, r = .96; Letter Comparison, r = .96; Number Series, r = .86; Cube Assembly, r = .71; and Name Number, r = .86. To provide an adjustment for guessing, all subsequent analyses used the variable of number correct minus number incorrect for the paper-and-pencil tests.

Preliminary Age (by decade) × Complexity Level analyses of variance (ANOVAs) were conducted on the data from the three computer-administered cognitive tests to determine whether the age relations varied according to task complexity (i.e., number of folds in Paper Folding, number of relations among elements in Matrix Reasoning, and presentation-test lag in Associative Memory). Perhaps because of the small number of trials at each complexity level, the Age × Complexity interactions were not significant with the decision accuracy measure in any of the tests. Moreover, this was also true in restricted samples of subjects who all had accuracy in the simplest condition (i.e., one fold, one relation, or Lag 0) above the mean from the entire sample. Only the means across all three complexity levels are therefore considered in subsequent analyses.

Scores from the paper-and-pencil speed tests and the mean response times in the Digit Symbol test with zero (DigSym-0) and nine (DigSym-9) symbols were converted to standard deviation units on the basis of the entire sample distribution and were plotted as a function of decade in Figure 1. Because the Digit Symbol measures are expressed in units of time per item rather than number of items in a fixed period of time, higher scores on these measures correspond to poorer performance. Inspection of Figure 1 reveals that the patterns with each measure are very similar in that the average in the decade of the 20s is about +.5 (or −.5 for the Digit Symbol measures) and the average in the decade of the 70s is about −1.0 (or +1.0 for the Digit Symbol measures). The tendency for the function for the Digit Symbol measures to be positively accelerated accounts for the presence of the significant quadratic age trends in these measures reported in Table 2.

The same type of conversion to standard deviation units was conducted for the measures of number correct minus number incorrect in the three paper-and-pencil cognitive tests, with the means by decade plotted in Figure 2. As in Figure 1, the age trends are nearly monotonic, with means that range from about +.5 in the decade of the 20s to between −.5 and −1.0 in the decade of the 70s.

Digit symbol. Mean reaction time and mean percentage of errors in the Digit Symbol test are plotted as a function of number of symbols and age decade in Figure 3. Both variables were analyzed by separate repeated measures ANOVAs in which age was categorized by decade and number of symbols was a within-subjects variable. Only the main effect of number of symbols was significant in the analysis of errors, $F(3, 720) = 19.38$, $MS_e = 3.21$. All three effects were significant in the analysis of re-

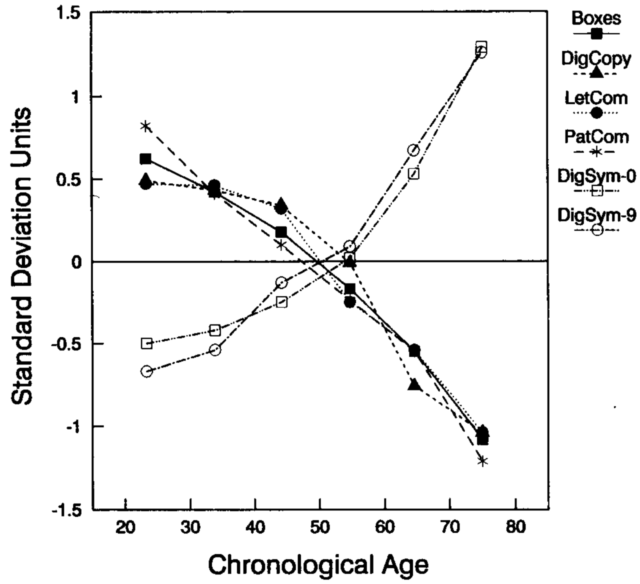

Figure 1. Mean standard deviation scores by decade for the speed measures, Study 1. DigCopy = Digit Copy; LetCom = Letter Comparison; PatCom = Pattern Comparison; DigSym-0 = Digit Symbol with zero symbols; DigSym-9 = Digit Symbol with nine symbols.

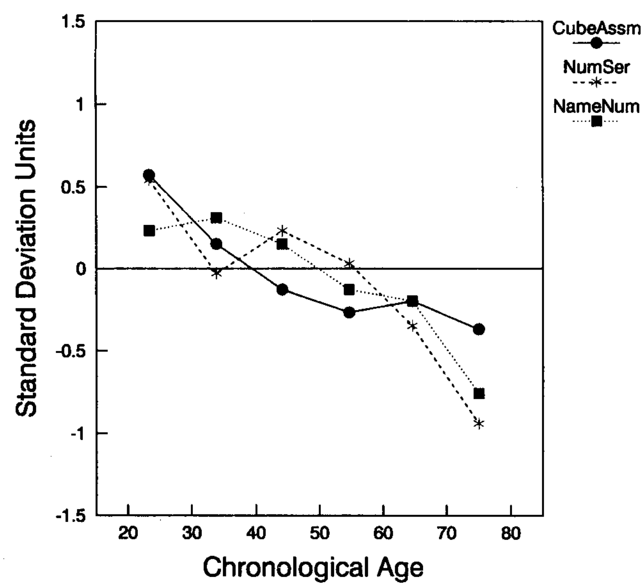

Figure 2. Mean standard deviation scores by decade for the number correct minus the number incorrect scores in three paper-and-pencil cognitive tests, Study 1. CubeAssm = Cube Assembly; NumSer = Number Series Completion; NameNum = Name–Number test.

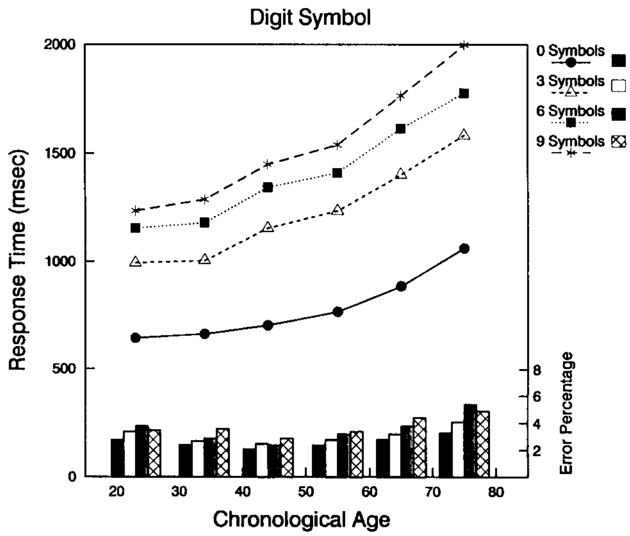

Figure 3. Mean reaction time and mean percentage of errors in the Digit Symbol Substitution test as a function of the number of digit-symbol pairs by decade, Study 1.

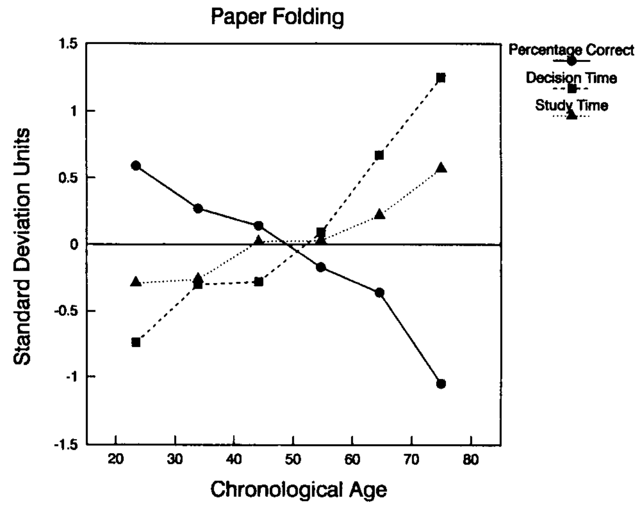

Figure 4. Mean standard deviation scores by decade for the study time, decision time, and decision accuracy measures in the Paper Folding test, Study 1.

sponse times: age decade, $F(5, 240) = 28.79$, $MS_e = 248{,}150$; number of symbols, $F(3, 720) = 1{,}799.20$, $MS_e = 14{,}100$; and Age Decade × Number of Symbols, $F(14, 720) = 9.02$, $MS_e = 14{,}100$. The pattern in Figure 3 suggests that the significant interaction in the response time variable is a consequence of larger age relations on trials with more symbols. The age correlations were consistent with this interpretation, as they were .51 for zero symbols, .59 for three symbols, .59 for six symbols, and .61 for nine symbols.

One manner in which the Digit Symbol test can be conceptualized is to assume that performance in the nine-symbol version of the test reflects processes of encoding, responding, and search of the code table, and that performance in the zero-symbol version of the test only requires processes of encoding and responding. According to this interpretation, the slope of the function relating the number of symbols to response time represents the time to decide to search the code table and to carry out the search. One or both of these processes should occur on one third, two thirds, or all of the trials when the code table contains three, six, or nine symbols, respectively. Regression equations relating number of symbols (between three and nine) to response time were therefore computed for each subject. The mean of the correlations was .95, indicating that the fit of the regression equations was generally good. The mean of the slope parameters was 51 ms per symbol. The intercept of these regression functions can be hypothesized to represent the time needed to respond when no search processes are required. The mean of the intercept parameters was 1,049 ms, which was substantially greater than the mean response time in the DigSym-0 condition (i.e., 760 ms). One possible interpretation of this discrepancy is that the additional time in the intercept parameter in relation to the actual time to respond with zero symbols represents uncertainty about when, and how, to search the code table.

Both the slope and the intercept parameters were larger with increased age (cf. Table 2), as was the difference between the intercept and the DigSym-0 time (i.e., age correlation = .22). These results suggest that increased age is associated with slower encoding and response processes (DigSym-0 and intercept), slower search of the code table (slope), and a longer time to decide to search the code table (difference between the intercept and DigSym-0).

Computer-administered cognitive tests. For each of the computer-administered cognitive tests, mean study time, mean decision time, and mean decision accuracy across all complexity levels were converted into z scores, and the means were plotted as a function of decade. Results from the Paper Folding test are illustrated in Figure 4, those from the Matrix Reasoning test in Figure 5, and those from the Associative Memory test in

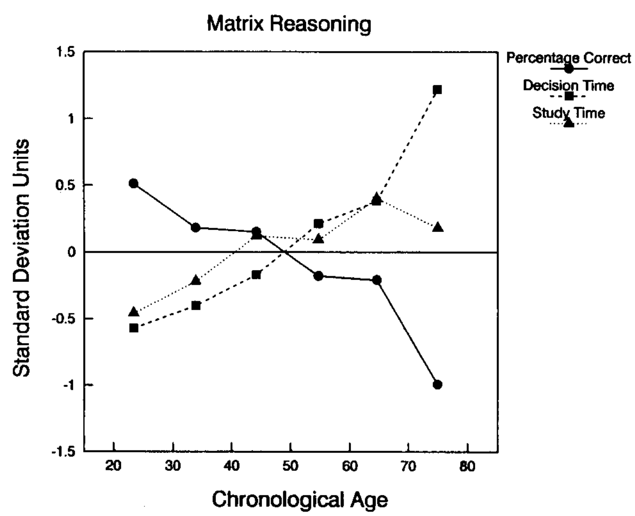

Figure 5. Mean standard deviation scores by decade for the study time, decision time, and decision accuracy measures in the Matrix Reasoning test, Study 1.