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What Do Adult Age Differences in the Digit Symbol Substitution Test Reflect?

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Results from three studies are reported in which adults between 18 and 84 years of age performed various versions of the Digit Symbol Substitution Test. The first study revealed that the age-related declines in digit-symbol performance were largely independent of both the amount of education the participants had received and their self-reported health status, and were characterized by a gradual shift in the entire distribution of scores with little age-related increase in variance. The age relations were greatly attenuated after statistical control of a composite measure of perceptual comparison speed, however, implying considerable commonalities between perceptual comparison speed and what the Digit Symbol Substitution Test measures. Two further studies indicated that young and old adults appeared to use similar strategies to perform the task, and were nearly equivalent in the proportions of time devoted to writing the responses and searching the code table.

THE Digit Symbol Substitution Test consists of a code table displaying pairs of digits and symbols, and rows of double boxes with a digit in the top box and nothing in the bottom box. The task for the examinee is to use the code table to determine the symbol associated with each digit, and to write as many symbols as possible in the empty boxes below each digit. Although the test seems quite simple, it may be important for the understanding of adult age differences in cognition because scores on it are highly correlated both with measures of intelligence and chronological age. In fact, the relations with intellectual measures are so strong that Wechsler has included it as one of the subtests in his adult intelligence scales. Correlations of digit-symbol score with full-scale intelligence score reported in the WAIS (Wechsler, 1955) and WAIS–R (Wechsler, 1981) manuals range from .51 to .74, with relatively little systematic variation in the magnitude of the correlations across the range from 18 to 74 years of age.

The relations between age and digit-symbol score are also large, as analyses of the WAIS (Birren & Morrison, 1961) and WAIS–R (Kaufman, Reynolds, & McLean, 1989) standardization data revealed correlations between age and digit-symbol score of $-.46$ and $-.54$, respectively. Similar age trends have also been reported with a symbol-digit version of the task in which digits are written instead of symbols. To illustrate, correlations between age and symbol-digit score have been reported to be $-.67$ for a sample of 172 adults (Emmerson, Dustman, Shearer, & Turner, 1989), $-.67$ for a sample of 125 adults (Gilmore, Royer, & Gruhn, 1983), and $-.77$ for a sample of 386 adults (Royer, Gilmore, & Gruhn, 1981).

In light of these strong relations with both intelligence and adult age, it seems likely that the Digit Symbol Substitution Test is measuring processes important to the relation between age and cognition. A potentially fruitful research agenda might therefore involve focusing on the causes and consequences of the processes responsible for age-related variations in digit-symbol performance.

Three hypotheses have been proposed in recent years to account for age-related differences in digit-symbol performance. What might be termed the peripheral motor speed hypothesis attributes most of the age differences to an age-related reduction in the speed of making manual movements, such as writing symbols. This interpretation is bolstered by the fact that writing speed has been found to decline with increased age (e.g., Birren & Botwinick, 1951), but it is weakened by its inability to explain the association between digit-symbol score and measures of higher order cognition. Several sets of empirical findings reported in the last 15 years are also inconsistent with the peripheral motor speed hypothesis. For example, Erber (1986), Erber, Botwinick, and Storandt (1981), Salthouse (1988), and Storandt (1976) all measured the speed with which individuals could merely copy symbols, in addition to the speed of substituting symbols for digits in the standard test. The ratios of the copying measures to the standard measures were nearly identical for young and old adults in each study [i.e., .44 for young adults and .42 for older adults in Erber (1986); .48 for young adults and .47 for older adults in Erber et al. (1981); .45 for young adults and .46 for older adults in Salthouse (1988); and .50 for young adults and .53 for older adults in Storandt (1976)]. These results are therefore consistent in indicating that both young and old adults devoted approximately the same proportion of their total performance time to writing the symbols.

Another set of results suggesting that writing speed is probably a minor factor contributing to the age differences in digit-symbol performance derives from studies with a modified Yes/No version of the digit-symbol task. Both Salthouse (1978) in a paper-and-pencil version, and Salthouse, Kausler, and Saults (1988) in a computer-administered version, found substantial age differences when the research participant was simply required to indicate whether the displayed digit-symbol pair was correct according to the code table. Age correlations in the two Salthouse et al. (1988) studies, in which the decisions were communicated by a keypress on a computer keyboard, were

.54 and .56 — values quite similar in absolute magnitude (but opposite in sign because they represent time per response rather than number of responses in a fixed time) to those reported in the studies cited earlier.

A second hypothesis proposed to account for the negative relations between adult age and digit-symbol performance invokes memory limitations as the critical factor. That is, it has been proposed that older adults may be less efficient at learning or remembering the association between the digit-symbol pairs than young adults, and consequently they must engage in more time-consuming searches of the code table during the performance of the task. This interpretation has the advantage of relying on a mechanism (memory limitations) that can be plausibly related to other cognitive functions and is consistent with the well-documented findings of reduced efficiency of paired-associate learning with increased age [e.g., Salthouse et al. (1988) recently reported correlations ranging from −.15 to −.42 between age and measures of paired-associate performance]. However, a number of results suggest that this interpretation is unlikely to provide a complete explanation of the negative relation between age and digit-symbol performance. Among the relevant studies is one by Erber et al. (1981) in which substantial age differences were still evident even after all the young and old research participants had learned the digit-symbol pairs to a criterion of perfect recall. There are also several reports that age differences either remain constant, or even increase, across 10 (Erber, 1976), 20 (Grant, Storandt, & Botwinick, 1978), and even 100 (Beres & Baron, 1981) repetitions of the task. The additional practice should have allowed many of the digit-symbol pairs to be committed to memory, and yet in none of these studies was there a significant reduction of the magnitude of the age differences with greater practice. Finally, Salthouse (1978) reported that the relative age differences remained constant when memory load was minimized by reducing the number of digit-symbol pairs from 9 to 6 to 3 to 1. If older adults devoted a larger proportion of their performance time to inspection of the code table than young adults, then reducing the number of entries in the code table should have benefited older adults more than young adults. The fact that this did not happen suggests that the two groups devoted approximately the same proportion of time to inspection and search of the code table.

The third hypothesis regarding the age relations on digit-symbol performance is that they are a reflection of an age-related slowing of many cognitive operations (Salthouse, 1985). That is, rather than representing a specific age-related deficit in one particular process, the age differences in digit-symbol performance may be a consequence of a rather global slowing of many perceptual, motor, and cognitive processes. Unlike the other hypotheses, this hypothesis currently has little directly relevant evidence, and instead has received consideration in large part because of the perceived limitations of the other hypotheses.

Each of the preceding hypotheses is reexamined in this report. Different methodologies are used to investigate the peripheral-motor and limited-memory interpretations than those used in the past, and the relation of digit-symbol performance to performance on other simple speeded tasks is examined as a means of investigating the hypothesis based on a relatively general age-related slowing.

Study 1

The rationale for the first study was that if age differences in digit-symbol scores primarily reflect an age-related slowing of many processing operations, then a substantial proportion of the age-related variance in digit-symbol performance should be eliminated by removing the variance associated with other speeded measures. The other measures of speed examined in this study involved comparisons of strings of letters or patterns of lines. Both tasks are very similar to those assumed to measure perceptual speed (e.g., Number Comparison, Identical Pictures) in that simple (same/different) decisions were to be made with respect to whether the two members of the pair were identical.

The availability of data from a relatively large ($N = 910$) sample of adults from a wide range of ages also allowed the exact nature of the age trends to be investigated. For example, two possibilities are that with increased age either (a) the entire distribution shifts toward lower scores or (b) an increasing percentage of people perform at relatively low levels, whereas the others maintain high levels of functioning. Negative relations between age and performance could be produced in each case, but the implications would be quite different. A shift in the entire distribution would suggest that most people are affected by the age-related processes, whereas a bimodal pattern would imply that only a portion of the relevant population was affected by the age-related influences.

Method

Subjects. — Research participants were recruited from newspaper advertisements requesting volunteers to participate in research projects concerned with memory and cognition. A total of 910 adults between 18 and 84 years of age participated in one of four separate projects with between 220 and 235 adults in each project. (No analyses of the digit-symbol data were described in the reports of these projects.) The mean age of the 910 adults (54% women) with complete data relevant to the current purposes was 48.8 years (SD = 17.3). The mean years of education was 15.4 (SD = 2.5), and the mean health rating on a 5-point self-assessment scale (1 = excellent, 5 = poor) was 2.1 (SD = 1.2). Correlations of these variables with chronological age were −.01 for education and .13 ($p < .01$) for self-rated health.

Procedure. — The WAIS–R Digit Symbol Substitution Test was administered along with other tests of perceptual comparison speed, memory span, working memory, and various types of cognition. Measures common across the four projects, besides the Digit Symbol Substitution Test, were: letter comparison, pattern comparison, computation span, and listening span. The letter comparison and pattern comparison tests consisted of pages containing pairs of 3, 6, or 9 letters, or patterns composed of 3, 6, or 9 line segments. One-half of the pairs were identical, and one-half were different (created by changing one of the letters or line segments from a correct pair). The task for the participant was to classify each pair as SAME or DIFFERENT, by writing an S or a D on a line between the two members of the pair, as rapidly as possible. Trials with 3, 6, or 9 elements were separately timed, and the scores averaged to provide a single measure for each type of comparison (letter or pattern). Because the time limits were 20 seconds per page in the first project and 30 seconds per page in the other projects, the scores from the participants in the first project were multiplied by 1.5 to make them comparable with those from participants in the other projects.

The computation span and listening span tasks were designed to assess working memory by requiring participants to remember information while also carrying out specified processing. In the computation span task, arithmetic problems were presented auditorily, and the task was to answer the arithmetic problem while also remembering the last digit in each problem. Short sentences were auditorily presented in the listening span task, with participants instructed to answer a question about the sentence while also remembering the last word in each sentence. The number of arithmetic problems or sentences presented on a trial increased from one to seven, with three trials at each sequence length. An individual's span was determined by the highest number of digits or words that could be remembered on at least two of the three trials for a sequence length, given that he or she was also correct in the answers to the relevant arithmetic and sentence comprehension questions. This latter requirement ensured that the scores represented both storage and processing.

RESULTS AND DISCUSSION

Digit-symbol scores in this sample correlated $-.54$ with chronological age. This value is quite close to those of the studies cited earlier, and the regression slope of $-.47$ items per year is also similar to the slope of $-.43$ reported by Emmerson et al. (1989) for the Symbol-Digit test. These results suggest that the present sample is probably representative of other samples of adults who participate in research projects of this type.

A multiple regression analysis with age and gender as variables revealed that both main effects and their interaction were significant (i.e., all F's > 8.4, $p < .01$). Separate analyses of the age relations for men and women indicated that the regression equations were 75.37 – .40 (years) with an r^2 of .25 for men, and 87.06 – .54 (years) with an r^2 of .35 for women. The interaction is therefore attributable to a higher initial level, but greater age-related decline, for women than for men.

The distribution of scores by decade is illustrated in Figure 1. It is apparent in these data that the negative age relations are associated with a shift in the entire distribution toward lower scores with increased age. There is little indication of a tendency toward bimodality with advancing age, and even the variance appears to remain relatively constant from the decade of the 20s through the decade of the 70s. Standard deviations for the six distributions illustrated in Figure 1 were 12.79, 13.60, 11.28, 15.04, 10.96, and 12.97, from the 20s through the 70s, respectively.

The two perceptual comparison speed measures had correlations with one another of .78, and the correlation between the two working memory measures was .59. Composite scores for each construct were created by averaging the z-scores for the letter comparison and pattern comparison measures for perceptual comparison speed, and averaging the z-scores for the computation span and listening span measures for working memory. Correlations of these composite measures with age were $-.64$ for perceptual comparison speed and $-.49$ for working memory, and those with digit-symbol score were .74 for perceptual comparison speed and .56 for working memory.

A series of hierarchical multiple regression analyses were conducted to examine the magnitude of the relations between age and digit-symbol performance before, and after, statistical control of other variables. Results of these analyses are summarized in Table 1. (The possibility that the variables might operate as moderators of the age relations was examined by means of cross-product interaction terms entered after the main effects in the regression equation. None of these interactions was significant.)

It can be seen in Table 1 that there was relatively little attenuation of the age relations after controlling the health and education variables. That is, 28.7% of the digit-symbol variance was related to age before controlling these variables, and 27.3% was still related to age after both variables were controlled. In contrast to the situation with the health and education variables, there was substantial reduction of the age relations after controlling the perceptual comparison speed variable. The 0.9% of the variance related to age after removing the variance associated with perceptual comparison speed was still statistically significant, but it is clearly quite small. It is also noteworthy that there was moderate attenuation of the age-related variance by control of the working memory variable, but it was smaller than that associated with perceptual comparison speed, and there was little it could add to the further attenuation of the age relations above that attributable to perceptual comparison speed.

Three major conclusions seem warranted from the results of this study. The first is that the large negative relations between age and digit-symbol performance are characterized

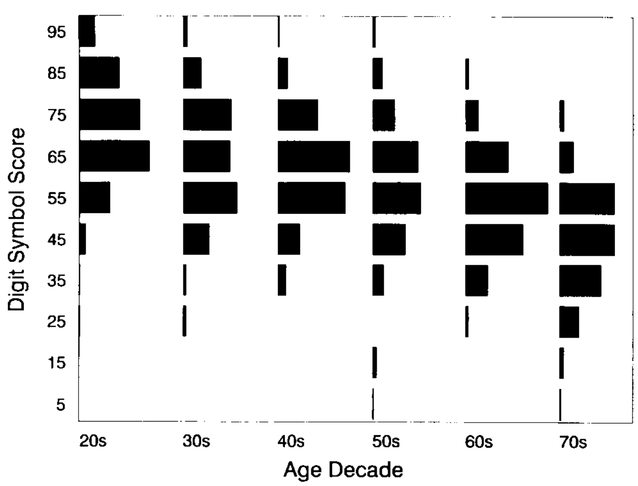

Figure 1. Distribution of WAIS–R Digit Symbol Substitution scores by decade. Between 129 and 169 adults are represented in each decade.

Table 1. Age-Related Variance in Digit-Symbol Performance Before and After Statistical Control of Other Variables, Study 1 (N = 910)

	Cumulative R^2	Increment in R^2	F for increment
Age	.287	.287	369.13*
Health	.025	.025	31.67*
Age	.295	.270	348.42*
Education	.043	.043	57.01*
Age	.329	.286	388.20*
Health	.025	.025	33.49*
Education	.060	.035	47.96*
Age	.333	.273	368.79*
Health	.025	.025	50.64*
Education	.060	.035	72.52*
Perceptual comparison speed	.550	.490	1001.62*
Age	.559	.009	19.20*
Health	.025	.025	38.24*
Education	.060	.035	54.75*
Working memory	.319	.259	399.15*
Age	.416	.097	150.67*
Health	.025	.025	52.62*
Education	.060	.035	75.35*
Perceptual comparison speed	.550	.490	1040.74*
Working memory	.572	.022	46.97*
Age	.576	.004	9.22*

*$p < .01$.

by a shift in the entire distribution, and do not appear to reflect a tendency for some older adults to have dramatically lower scores while others continue to perform like the majority of young adults. Although there are some relatively high-performing older adults, there are also a number of low-performing young adults, and the age-related reduction in the mean level of performance was not associated with an increase in the variance of the distribution.

The second conclusion is that the age relations in this sample are largely independent of self-reported health status and amount of education. This does not mean that the factors of health and education have no effect on the age trends in digit-symbol performance because the range of variation in the health and education measures was rather restricted. However, as the values in this sample were at the high end of the scales, it can be inferred that the substantial negative relations between age and digit-symbol performance are not an artifact of age differences in health or education, because those relations are evident even among highly educated adults who report themselves to be in good to excellent health.

The third major conclusion from the results of this study is that there is considerable commonality in the age-sensitive aspects of the digit-symbol test and the age-sensitive aspects of the perceptual comparison tasks. That is, statistical control of the composite measure of perceptual comparison speed resulted in a 96.7% attenuation (i.e., from 27.3 to 0.9%) of the age-related variance in Digit Symbol Substitution Test performance. These results suggest that whatever characteristic of the digit-symbol task that is contributing to the large negative relations between age and digit-symbol performance is also present in the perceptual comparison tasks. Because the perceptual comparison tasks are superficially quite distinct from the digit-symbol task, this finding provides convergent evidence for the hypothesis that age differences in the digit-symbol test are a reflection of an age-related slowing of many processing operations. The next two studies were designed to provide discriminant evidence in the form of results inconsistent with interpretations based on factors related to writing speed or memory limitations.

Study 2

Although the results of Study 1 appear convincing in indicating that many of the age-related differences in digit-symbol performance are associated with the same processes responsible for age differences in simple perceptual comparison tasks, the analyses are limited by the coarseness of the measure of number of correct substitutions. A primary motivation for this study was the assumption that more detailed examination of the processes involved in performance of the digit-symbol task might be possible by implementing the task on a computer. That is, because the computer can preserve complete information about responses to individual digit-symbol pairs, the data can be analyzed to determine the relations between median response time and the serial position of the target digit in the code table. This information can, in turn, be used as an indication of the search strategy used by the individual, or his or her reliance on memory of the digit-symbol pairs while performing the task. As an example, if young adults have less need than older adults to refer to the code table to retrieve the digit-symbol pairing, then their serial position functions might be expected to be flatter than those of older adults.

Because data are to be collected from both the paper-and-pencil and computer versions of the digit-symbol task, it is also of interest to examine the relations between the two performance measures. Both the correlation and the ratios of the time per response can be investigated. The correlation indicates the extent to which the two measures reflect common processes, and the ratio is informative about the relative time required to write symbols (in the paper-and-pencil version) as opposed to merely pressing one of two keys (in the computer version). If the peripheral-motor hypothesis is correct, then older adults should have much smaller ratios of scores in the computer version to scores in the paper-and-pencil version than young adults because a greater proportion of their response time is devoted to writing the symbols.

Method

Subjects. — Data were available from a total of 135 young adults and 80 older adults. Young adults were college students who received extra credit in a psychology course for their participation. Older adults were recruited from newspaper advertisements and referrals from other participants. The age range of the young adults was 17 to 28 years, with a mean of 19.7, and that for the older adults was 51 to 80 years, with a mean of 64.5. Forty-six percent of the young adults were women, as were 55% of the older adults. The average years of education were 13.6 (SD = 1.3) for young adults and 15.7 (SD = 2.2) for older adults, and the mean self-assessed health ratings (on a scale from 1 = excellent to 5 = poor) were 1.5 (SD = 0.7) for young adults and 1.8 (SD = 0.9) for older adults.

Procedure. — The WAIS–R Digit Symbol Substitution Test and a computer-controlled version of this test were administered, in this order, to the individuals before they participated in one of several experiments concerned with working memory. The computer version of the test consisted of a display of the standard digit-symbol code table at the top of the screen, and a display of a single digit-symbol pair centered in the middle of the screen. The code table remained constant across trials but the digit-symbol pair changed from trial to trial. On one-half of the trials, the digit-symbol pair was correct, in that it corresponded to the association represented in the code table, and on one-half of the trials it was incorrect. The task for the participant was to classify the pairs as CORRECT or INCORRECT as rapidly as possible by pressing the "/" key on the keyboard for CORRECT, and by pressing the "Z" key on the keyboard for INCORRECT. A practice sequence of 20 trials was presented followed by the experimental sequence of 90 trials (consisting of a random arrangement of 5 CORRECT and 5 INCORRECT trials for each of the 9 digits).

Results and Discussion

The age differences in performance on the paper-and-pencil digit-symbol task in this sample were similar to those in other studies as the age correlation was −.61, with a regression slope of −.41 items per year. Median time per response in the computer version had a correlation with age of .75, and a correlation of −.73 with the score on the standard Digit Symbol Substitution Test. Accuracy in the computer version was very similar in the two groups (i.e., 94.9% for young adults and 95.9% for older adults), and thus was not analyzed further. Neither health, education, nor gender was responsible for significant mediation (attenuation) or moderation (interaction) of the age relations, and thus these variables were also ignored in subsequent analyses.

Two multiple regression analyses were conducted to estimate the amount of age-related variance in the standard paper-and-pencil scores. The initial analysis, with age as the only predictor, yielded an R^2 for age of .376, $F(1,210) = 126.30, p < .01$. In the second analysis, the median time per response in the computer version of the digit-symbol task was entered as a predictor before age. This analysis revealed that age was only associated with an increment in R^2 of .009, $F(1,209) = 3.90, p < .05$. As in the previous study, therefore, it appears that most of the age-related variance in digit-symbol performance is shared with a different task, and in this particular case it is one that does not even share the same kind of response.

Estimates of the relative amount of time devoted to processes other than writing the symbols were derived by converting scores on the standard paper-and-pencil test into time per item, and then dividing these values into the median time per response in the computer version of the test. These ratios averaged .83 for young adults and .94 for older adults (z = 4.76, $p < .01$), suggesting that the young adults devoted approximately 17% of their average response time to writing, whereas only 6% of the total response time of older adults was attributable to processes related to writing. However, interpretation of this result is complicated by a confounding of task version with order of presentation. That is, because the computer version was always performed after the paper-and-pencil version, the difference in ratios could reflect greater learning from the first to the second test on the part of young adults rather than a greater percentage of time devoted to writing. Unfortunately, these two factors could not be distinguished within the present design. It is nevertheless important to note that there is no indication in these data that the requirement to write the symbols exerted more of an influence on older adults than on young adults, and in this respect the results are consistent with those of the studies cited earlier (Erber, 1986; Erber et al., 1981; Salthouse, 1988; Storandt, 1976) in which young and old adults were found to have similar ratios of symbol-copying to digit-symbol substitution performance.

Median response times in the computer version of the test were analyzed according to target digit (or serial position in the code table) and trial type (positive or negative). These data are illustrated in Figure 2, and results of the Age × Target Position × Trial type analysis of variance (ANOVA) are summarized in Table 2.

It is evident in Figure 2 that the serial position functions for responses on positive trials were similar for young and old adults. In both groups, the pattern is for response times to be somewhat faster than average for digits at the extreme positions (i.e., 1 and 9) and for the digit 6. The advantage of the digits at the end positions is probably attributable to a strategy of searching the code table in an outside-in manner, and responses to the digit 6 are likely fast because the associated symbol (0) is distinctive and easily remembered. The most important point regarding the serial position effects, however, is that they appear very similar in the two

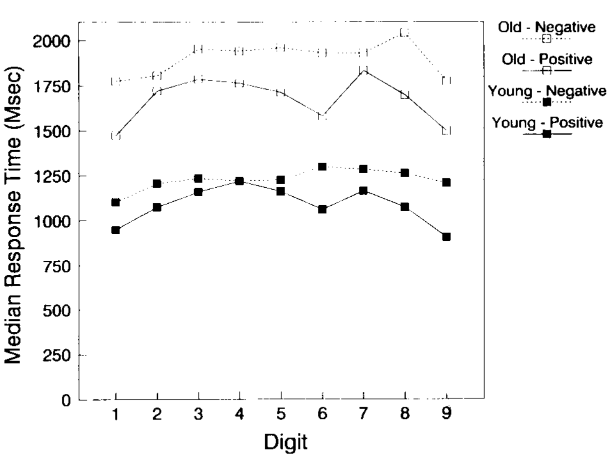

Figure 2. Median response time as a function of target serial position and trial type for the computer digit-symbol task in Study 2. Each data point represents the median of an average of 5 responses for 135 young adults or 80 older adults.

Table 2. ANOVA Results from Studies 2 and 3

	Study 2	Study 3	
	Digit-Symbol	Digit-Symbol	Digit-Digit
Age (young vs. old)			
F	206.03*	27.36*	26.26*
df	1,211	1,78	1,78
MSe	1738	2295	637
Position (of target digit in code table)			
F	35.53*	12.70*	1.94
df	8,1688	8,624	8,624
MSe	78	88	18
Age × position			
F	2.38	0.82	1.12
df	8,1688	8,624	8,624
MSe	78	88	18
Trial type (positive vs. negative)			
F	289.90*	79.27*	101.22*
df	1,211	1,78	1,78
MSe	107	148	35
Age × trial type			
F	15.56*	0.08	1.69
df	1,211	1,78	1,78
MSe	107	148	35
Position × trial type			
F	8.67*	2.24	1.90
df	8,1688	8,624	8,624
MSe	81	90	16
Age × position × trial type			
F	2.63*	1.83	0.34
df	8,1688	8,624	8,624
MSe	81	90	16

*$p < .01$.

groups, and the Age × Position interaction was not significant.

Negative responses were generally slower than positive responses, and the absolute difference between the two types of trials was larger for older adults than for young adults, as reflected by the significant Age × Trial type interaction. It should be noted, however, that the trial type difference was very similar in the two groups when expressed in proportional terms. That is, ratios of times for negative trials to times for positive trials averaged 1.13 for young adults and 1.14 for older adults ($z = -.55$).

The major findings of this study were that the computer-controlled version of the Digit Symbol Substitution Test yielded measures exhibiting a similar magnitude of relation to chronological age as the standard version, and also provided information relevant to the strategies used to perform the task. The lack of age differences in the serial position patterns and the constant proportion of negative to positive response times in the two groups suggest that young and old adults performed the task in a similar manner.

Study 3

The serial position effects in Study 2 were interpreted as a reflection of the strategy used by the research participant to search the code table for the correct digit-symbol pairing. However, because the order of the digits in the code table was fixed (i.e., in a 1 to 9 sequence), it is possible that the serial position effects actually represent differences in response times to specific digits. This alternative interpretation can be investigated by examining the serial position functions in a version of the task in which no inspection of the code table is required. If the serial position effects are attributable to variations associated with specific digits, and not to the position of the digit within the code table, then those effects should still be evident in this modified version of the task. In contrast, flat serial position functions would be expected in this task if they originate because of the manner in which the code table is searched.

Two computer-controlled tasks were therefore administered in this study — the digit-symbol task of Study 2 and a new digit-digit task. The digit-digit task was identical to the digit-symbol task, except that no symbols were presented and, thus, there was no need to refer to the code table to evaluate the correctness of the pair.

The availability of performance measures from similar tasks differing in the need to rely on the code table also provides an opportunity to examine the role of memory processes in digit-symbol performance. That is, the magnitude of the correlation between the digit-symbol and digit-digit measures should indicate the extent to which they reflect common processes, and the ratio of digit-digit to digit-symbol performance should be informative about the relative time needed to refer to the code table.

Method

Subjects. — A total of 131 adults between 21 and 80 years of age (mean age = 46.5 years, SD = 15.6) contributed data to this study. All research participants were males recruited from letters and other contacts to groups presumed to have moderate to extensive experience using spatial visualization abilities. The average number of years of education was 16.2 (SD = 2.1), and the average self-assessed health rating was 1.4 (SD = 0.6).

Procedure. — The two tasks reported here were performed immediately after participating in a study concerned with influences of age and experience on spatial visualization abilities. The digit-symbol task was identical to the computer-controlled task described in Study 2. The digit-digit task had a similar format but no symbols were displayed. That is, the code table consisted of repetitions of the digit from the top box in the bottom box, and the probe displays consisted of two digits that were either the same (on 50% of the trials) or different (on 50% of the trials). All participants performed the digit-symbol task before the digit-digit task.

Results and Discussion

Median times in the digit-symbol and digit-digit tasks averaged 1.51 and 0.67 seconds, respectively. Because accuracy was high (i.e., 94.8% in the digit-symbol task and 97.6% in the digit-digit task), it was not considered further. The two time measures correlated .61 with each other, and had age correlations of .53 for the digit-symbol measure and .50 for the digit-digit measure. Neither health nor education was significantly correlated with either digit-symbol time or digit-digit time and, thus, these variables were ignored in subsequent analyses.

Hierarchical regression analyses revealed that the age-related variance in the digit-symbol measure was reduced from 27.7 to 6.4% after controlling the variance associated with the digit-digit measure. This result is similar to that of Study 1 in indicating that there is considerable overlap in the age-related variance in measures of digit-symbol performance and in measures of performance in simple perceptual comparison tasks.

The ratio of median time in the digit-digit task to that in the digit-symbol task averaged .43, indicating that processes concerned with determining whether the pairing of digit and symbol was correct required an average of about 57% [i.e., (1.0 − .43) × 100] of the total response time. The correlation of this ratio with age was only .007, indicating that the proportional time devoted to evaluating the digit-symbol association remained quite constant from about age 20 to age 80.

The sample was divided into three groups, and performance of the 38 young adults (age 21 to 34, mean age = 28.2 years) and 42 older adults (age 56 to 80, mean = 65.3 years) contrasted in a manner similar to Study 2. The serial position functions for positive and negative trials in the digit-symbol and digit-digit tasks are illustrated in Figure 3, and the results of the ANOVA are summarized in Table 2.

Two results from Figure 3 and Table 2 are especially important to note. The first is that the serial position functions for the digit-symbol task closely resemble those of Study 2. The major difference seems to be that the times of the young adults in the current study are slower than those of the young adults in Study 2, perhaps because the average age of the young adults in this sample was almost 9 years greater than that of the young adults in the earlier sample.

The second interesting aspect of the results in Figure 3 is

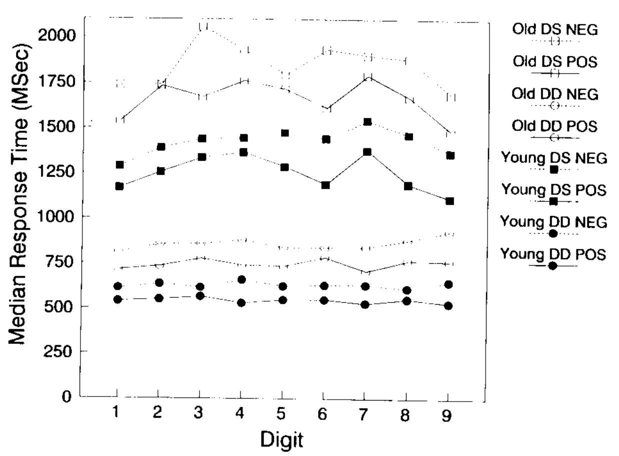

Figure 3. Median response time as a function of target serial position and trial type for the computer digit-symbol (DS) and computer digit-digit (DD) tasks in Study 3. Each data point represents the median of an average of 5 responses for 38 young adults or 42 older adults. NEG, negative; POS, Positive.

that there was no evidence of a serial position effect in the response times in the digit-digit task. As mentioned previously, this finding is consistent with the interpretation that the serial position effects in the digit-symbol task reflect processes associated with search of the code table and are not attributable to factors specific to particular digits.

General Discussion

The results of these studies lead to two major conclusions concerning the relation between age and performance on the Digit Symbol Substitution Test. The first conclusion, based on the results of Study 1, is that the age trends are produced by a gradual shift of the entire distribution of scores. This is a somewhat surprising finding, because it is occasionally suggested that negative relations between age and performance on various cognitive tests are a consequence of a small number of people experiencing rather pronounced impairments with increased age, with many people continuing to perform at the level of young adults (Albert, 1988; Lachman, 1986; Schaie, 1988). The patterns evident in Figure 1 are clearly incompatible with this interpretation, and instead are more consistent with a view that the age-related decline in digit-symbol performance is normative or typical of most individuals. Of course, longitudinal information is needed to reach definitive conclusions about patterns of individual aging, but the discovery that the age-related declines in this test are characterized by a gradual repositioning of the entire distribution, with little or no increase in interindividual variability, indicates that the negative relations are not simply attributable to the presence of a few very low scores on the part of a small number of older adults.

The second major conclusion is that the age differences in digit-symbol performance primarily seem to reflect a slower rate of processing information, and not deficits in memory or in the efficiency of specific processes. Two sets of results lead to this conclusion. One set consists of the findings in Studies 1 and 3 that a large proportion of the age-related variance in digit-symbol performance is shared with measures of simple perceptual comparison speed. Of related interest are the high correlations between the digit-symbol and perceptual comparison speed measures in Study 1 (i.e., $r = .74$), between the paper-and-pencil and computer digit-symbol measures in Study 2 (i.e., $r = -.73$), and between the computer digit-symbol and computer digit-digit measures in Study 3 (i.e., $r = .61$). [In order to place these values in proper context, it should be noted that Wechsler (1981) reported that the test-retest reliability coefficient for the digit-symbol score is .82.] Because the common element in the paper-and-pencil digit-symbol substitution, letter comparison, pattern comparison, computer digit-symbol, and computer digit-digit tests seems to be the speed with which elementary operations can be executed, it appears reasonable to infer that a major factor contributing to the age sensitivity of digit-symbol performance is the speed of carrying out simple processing operations.

The other set of results supporting the conclusion that age differences in digit-symbol performance are largely attributable to reductions in the speed of processing are those concerned with the influence of search or decision processes, memory processes, and factors related to writing speed or manual dexterity. The results of Studies 2 and 3, and those of the other studies cited earlier, are remarkably consistent in indicating that these processes make the same relative contribution to the performance of young and old adults. Estimates of the magnitude of the effects of manipulations designed to investigate these factors are sometimes greater among older adults in absolute terms, but the relative contribution has generally been found to remain constant across adults of different ages. This is precisely the pattern one would expect if increased age is associated with an approximately proportional slowing of many elementary processing operations.

It was mentioned in the introduction that the Digit Symbol Substitution Test may have special significance because scores on this test are strongly related both to chronological age and to a variety of other measures of cognition and intelligence. If, as the results of these studies seem to indicate, it really is the case that the age relations on this test reflect a slowing in the rate of performing basic operations, then a worthy goal for future research is to determine whether a similar mechanism is responsible for the relations between measures of cognitive functioning and both age and digit-symbol performance.

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