Differential Age-Related Influences on Memory for Verbal-Symbolic Information and Visual-Spatial Information?

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A KEY issue in research on cognitive aging is the existence of selective or differential deficits in which the age-related effects on some cognitive measures are greater than those on other measures. As an example, it is sometimes claimed that the age-related effects are larger on measures of performance from tasks involving spatial information than on measures of performance from tasks involving verbal information. If this characterization is valid, then it would be consistent with the hypothesis (e.g., Goldstein & Shelly, 1981; Klisz, 1978) that the right hemisphere is more sensitive to age-related effects than the left because the right hemisphere is often postulated to be more specialized for visual-spatial processing than the left hemisphere. Findings of this type are potentially important because they might allow closer linkages between brain and behavior than has been possible in the past.

Although results suggestive of a differential deficit can be quite informative, previous comparisons of age differences in verbal and spatial information processing have been weak for at least three reasons. First, several of the comparisons have involved a confounding of type of information with other factors because the measures have often been derived from tasks that differ in numerous dimensions in addition to the type of information. For example, among the contrasts that have been cited as indicative of differential age-related effects on verbal and spatial processing are letter span vs perceptual closure tasks (Kinsbourne, 1974), and the WAIS-R Verbal vs the WAIS-R Performance scales (Klisz, 1978). Different patterns of age trends on these tests have led to speculations of differential or selective aging of verbal and spatial information processing and also of left and right hemispheric functioning (e.g., Klisz, 1978). However, tests such as these often differ in the role of previous knowledge, in the familiarity or amount of experience with the stimulus materials, in the presence of time limits, in the mode of response (e.g., oral or manual), and possibly in the amount of current processing required to produce a response. Because of these confoundings, it is difficult to determine whether it is the type of information or these other aspects of the task that contribute to any differential age relations that might exist.

Several studies have been reported in which age differences have been examined with verbal and spatial tasks designed to be equivalent except for the type of information. Unfortunately, the results from those studies have been mixed. For example, there are some reports of equivalent age differences for nearly parallel tasks involving verbal and spatial information (Schear & Nebes, 1980; Shelton, Parsons, & Leber, 1982), but there is at least one report of larger age differences with a visual-spatial task than with a presumably comparable task involving verbal information (Tubi & Calev, 1989).

A second limitation of much of the earlier research investigating age-related effects on tasks involving verbal and spatial information is that the assessment of the constructs has been narrow, and hence construct validity may have been weak. That is, many of the contrasts in previous studies have been at the level of single measures rather than at the more meaningful level of theoretical constructs. Any given measure is only an indirect, and hence confounded, indicator of the relevant theoretical construct because it is also influenced by the specific methods, materials, and measures used in the assessment of the construct. Because these other influences cannot be separated from the theoretical construct unless converging operations and multiple indicators are available, it is generally desirable to rely on two or more measures to attempt to unconfound the assessment of the construct from its specific operationalization. Reliance on multiple measures also has the advantage of broadening the assessment of the construct, which will likely increase the generality of the results.

The third limitation of much of the past research comparing age-related effects on verbal and spatial tasks is that the comparisons have relied on a single analytical procedure, namely, analysis of variance focusing on the Age × Task interaction. This is unfortunate because numerous concerns...
have been raised about the meaningfulness of statistical interactions (e.g., Salthouse, 1991), especially when there are age differences in the baseline level of performance, and when little information is available about the form of the construct-variable relation or the discriminating power (e.g., reliability, range in the measurement scale, cf., Chapman & Chapman, 1973) of the variables.

At least two alternative analytical procedures can be used to investigate differential age-related effects. One consists of conducting the analysis of variance (ANOVA) on scores expressed in standard deviation units derived either from the data of one of the age groups or from the data of a separate reference sample. In addition to minimizing across-measure differences in variability, this form of standardization has the advantage of providing a meaningful index of the degree of overlap of the scores in a relevant distribution. An example described in Salthouse (1991, pp. 298–299) illustrates that outcomes of the analyses can be quite different when this type of comparison is used instead of the traditional analysis of variance on the original scores.

A second alternative method of investigating differential or selective age-related effects involves examining the amount of independent age-related variance in each variable to determine if the variables have distinct and unique age-related influences (Salthouse & Coon, 1994). That is, rather than focusing on the size of the age differences in either original or standardized units, this type of analysis is concerned with the extent to which the age-related influences in one variable are independent of those in another variable. In particular, if there are significant increments in the proportion of variance (i.e., R²) associated with age in the spatial measures after the variance in the verbal measures was controlled, then one could infer that at least some of the age-related effects in the spatial measures were independent of (i.e., unique and distinct from) those in the verbal measures. An additional advantage of regression-based measures is that because they provide estimates of both the unique and the shared age-related variance, the relative amounts of each type of influence can be determined. Information of this nature is valuable in providing quantitative estimates of the contribution of each kind of influence, instead of simply indicating whether either effect is significantly different from zero.

The primary goal of the present study was to investigate the relation between age and measures of performance in verbal and spatial memory tasks without the problems identified above. Nearly parallel verbal and spatial memory tasks were designed, and the data were analyzed with several different analytical procedures, including ANOVAs on original and standardized scores, and analyses of the amounts of age-related variance in each variable that was independent of the variance in the other variable. In addition, multivariate analyses were conducted to examine relations at the level of theoretical constructs rather than only at the level of observable or manifest variables.

A secondary goal of the current project was to examine the influence of processing speed on the age differences in tasks with different kinds of information and processing requirements. Because previous studies have found that a large proportion of the age-related variance in a variety of memory and cognitive variables is shared with measures of processing speed (e.g., Salthouse, 1992, 1993a, 1994a), the data in this study were examined to determine whether similar relations would be evident with new combinations of speed and memory variables.

To summarize, adults from a wide range of ages were administered parallel versions of three memory tasks involving verbal-symbolic or visual-spatial information. The primary question was whether, across several different analytical procedures and measures, there is evidence of greater age-related influences on measures based on visual-spatial information processing than on measures based on verbal-symbolic information processing. In order to provide a separate sample for standardization purposes, 100 college students also performed the same battery of tests.

**METHOD**

**Subjects.** — Demographic characteristics of the student and adult samples, with the latter divided into double-decade categories, are summarized in Table 1. It is apparent that the research participants had an average of 1 to 2.5 years of education beyond high school and that their average health rating was in the very good range. Although these characteristics are typical of participants in research studies of this type, both samples are undoubtedly positively biased in educational level, and possibly health status, relative to the general population.

**Procedure.** — In addition to the tasks described below, most of the participants in this project also performed two tasks that are not discussed in this report. One was a computer-administered version of the Trail Making test, and the other was a computer-administered associative learning test. Results from these tests will be combined with additional data from other studies and described in separate reports.

The first four tests were administered with paper-and-pencil procedures and were designed to assess sensory-motor speed (Boxes, Digit Copying) and perceptual-comparison speed (Letter Comparison, Pattern Comparison). Each test consisted of a page of instructions and examples and a single test page. The task in the Boxes test was to create as many boxes as possible by drawing the

<table>
<thead>
<tr>
<th>Table 1. Demographic Characteristics of Samples, by Age Groups</th>
</tr>
</thead>
<tbody>
<tr>
<td>Students</td>
</tr>
<tr>
<td>----------</td>
</tr>
<tr>
<td>Age</td>
</tr>
<tr>
<td>% Female</td>
</tr>
<tr>
<td>Education</td>
</tr>
<tr>
<td>Health</td>
</tr>
</tbody>
</table>

*Note. Education refers to years of formal education completed, and health refers to self-rating on a 5-point scale (1 = Excellent, 5 = Poor).*
fourth line in three-sided figures. The task in the Digit Copying test was to copy digits from an upper square into a lower square. In both of these tests the measure of performance was the number of items completed in 30 sec. The Letter Comparison test consisted of 21 pairs of letters which were to be classified as same or different by writing an S or a D on the line between the members of the pair. The Pattern Comparison test consisted of 30 pairs of line patterns which were to be classified as same or different by writing an S or a D on the line between the members of the pair. In both of these latter tests, in order to adjust for guessing, the measure of performance was the number of correct responses minus the number of incorrect responses written in 30 sec.

The two reaction time tasks involved physical identity judgments with respect to a pair of letters or a pair of unfamiliar symbols. The symbols were similar in size to the letters because both sets of stimuli were constructed from an 8 x 8 matrix. The stimulus pair was presented in a vertical arrangement in the middle of the computer display, together with a reminder that the ‘‘/’’ key was to be pressed for same decisions and the ‘‘Z’’ key was to be pressed for different decisions. An initial practice block of 18 trials was administered with each type of stimuli, followed by blocks of 45 trials each with letters, symbols, symbols, and letters. Both accuracy and reaction time (RT) in msec were recorded, but because mean accuracy was greater than 96% with both types of stimuli, only the RT results were analyzed further.

Figure 1 is a schematic illustration of the sequence of events in the two versions of the three memory tasks. Each of these tasks was administered with two blocks of practice trials, a block of trials in the verbal condition, two blocks of trials in the spatial condition, and a final block of trials in the verbal condition.

Trials in the Matrix Memory task were preceded by a reminder on the screen concerning the type of information (identities or positions of the target items) that was to be remembered. The matrix stimulus, consisting of 7 shaded letters in an array of 25 letters, was then presented for 3 sec. This was followed by the response display, which consisted of seven horizontal lines in the verbal condition, and a blank matrix in the spatial condition. Responses were entered by typing the letters in the verbal condition and by using arrow keys, followed by pressing the space bar, to indicate target positions in the spatial condition. In both conditions the participants were required to produce seven unique responses on each trial to eliminate biases against guessing. Each experimental block consisted of five trials, and there were two trials in each practice block.

Trials in the Element Memory task consisted of a 2-sec presentation of a complex stimulus, a .5-sec interval with a blank display, and then the presentation of a probe stimulus. The task was to decide whether the probe stimulus had previously been an element in the complex stimulus. The complex stimuli in the verbal condition consisted of seven randomly selected letters, and the probe stimulus was a single letter. The complex stimuli in the spatial condition consisted of seven connected line segments forming a pattern, and the probe stimulus was a single line segment. In both conditions the probe stimulus was an element of the complex stimulus (i.e., one of the seven letters, or one of the line segments in the same position in the array) on 50% of the trials. Responses were communicated by pressing the ‘‘/’’ key for YES, and pressing the ‘‘Z’’ key for NO. Each practice block contained five trials, and the experimental blocks each contained 50 trials.

The Keeping Track tasks were based on those described by Salthouse, Babcock, and Shaw (1991). In each condition, a trial began with the presentation of an initial value (i.e., a digit, or an asterisk in a particular spatial location) in each of two squares. A series of transformations was then presented requiring the subject to update the status of the relevant variable by carrying out the specified arithmetic operation, or by repositioning the asterisk according to the length and direction of the displayed arrow. Finally, a question mark appeared in one of the squares indicating that the current value of that variable should be reported. The response consisted of typing the number in the numeric (verbal-symbolic) condition and using arrow keys to position a cursor in the final location of the target in the spatial condition. The measure of performance was the percentage error in the verbal-symbolic condition and an index of error magnitude in the spatial condition (in the form of the mean distance in a Cartesian coordinate system between the cursor
position and the correct target position). The stimulus durations, .75 sec per display for numeric information and 1.5 sec per display for spatial information, were selected from the results of the Salthouse et al. (1991) studies to yield moderate levels of accuracy in both young and old adults. Practice blocks consisted of three trials each, and there were 15 trials in each experimental block.

RESULTS

Students

Means, standard deviations, and estimates of reliability (obtained by boosting the correlation between the measures from the two trial blocks by the Spearman-Brown formula) for the student data are presented in Table 2. It can be seen that the reliabilities are generally in the moderate range, with the lowest value of .60 for the matrix memory-spatial variable.

Relations among the variables were examined with confirmatory factor analyses (Jöreskog & Sörbom, 1993). Based on earlier research (Earles & Salthouse, 1995; Salthouse, 1995b), the speed measures were hypothesized to form three factors: Boxes and Digit Copying comprising a Sensory-Motor Speed factor; Letter Comparison and Pattern Comparison comprising a Perceptual Comparison Speed factor; and Reaction Time-Letters and Reaction Time-Symbols comprising a Reaction Time Speed factor. The confirmatory factor analysis indicated that the hypothesized structure provided a good fit to the data (i.e., $\chi^2$ (df = 6, N = 100) = 4.56; RMR = .026; GFI = .98; AGFI = .95). Correlations between the factors were .73 ($SE = .13$) between Sensory-Motor Speed and Perceptual Comparison Speed; .33 ($SE = .11$) between Sensory-Motor Speed and Reaction Time Speed; and .48 ($SE = .12$) between Perceptual Comparison Speed and Reaction Time Speed.

Two memory factors corresponding to verbal (i.e., matrix memory-verbal, element memory-verbal, and keeping track-verbal) and spatial (i.e., matrix memory-spatial, element memory-spatial, and keeping track-spatial) information were hypothesized for the memory variables. The confirmatory factor analysis indicated that the hypothesis of Age x Condition analysis of variance conducted on the original scores was also conducted on these standardized scores from the student distribution to provide common units for comparison. The means in each of three age groups are plotted in Figure 2 for the six memory variables. The same type of Age x Condition analysis of variance conducted on the original scores was also conducted on these standardized scores.

Table 2. Characteristics of Variables in Student Sample (n = 100)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>SD</th>
<th>Est. Rel.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boxes</td>
<td>52.3</td>
<td>15.8</td>
<td>—</td>
</tr>
<tr>
<td>Digit Copying</td>
<td>56.7</td>
<td>8.4</td>
<td>—</td>
</tr>
<tr>
<td>Letter Comparison</td>
<td>12.0</td>
<td>2.8</td>
<td>—</td>
</tr>
<tr>
<td>Pattern Comparison</td>
<td>20.5</td>
<td>3.6</td>
<td>—</td>
</tr>
<tr>
<td>Reaction Time-Letters</td>
<td>554</td>
<td>86</td>
<td>.73</td>
</tr>
<tr>
<td>Reaction Time-Symbols</td>
<td>579</td>
<td>85</td>
<td>.88</td>
</tr>
<tr>
<td>MMV</td>
<td>6.28</td>
<td>0.49</td>
<td>.75</td>
</tr>
<tr>
<td>MMS</td>
<td>5.12</td>
<td>0.78</td>
<td>.75</td>
</tr>
<tr>
<td>EMV</td>
<td>86.0</td>
<td>9.0</td>
<td>.78</td>
</tr>
<tr>
<td>EMS</td>
<td>71.7</td>
<td>12.6</td>
<td>.89</td>
</tr>
<tr>
<td>KTV</td>
<td>0.38</td>
<td>0.18</td>
<td>.68</td>
</tr>
<tr>
<td>KTS</td>
<td>2.61</td>
<td>0.86</td>
<td>.82</td>
</tr>
</tbody>
</table>

Notes. MMV = matrix memory-verbal; MMS = matrix memory-spatial; EMV = element memory-verbal; EMS = element memory-spatial; KTV = keeping track-verbal; KTS = keeping track-spatial. Maximum scores in the memory tasks were 7.0 in the MMV and MMS tasks, 100.0 in the EMV and EMS tasks, and 0.0 (no errors) in the KTV and KTS tasks.

Table 3. Characteristics of Variables in Adult Sample (n = 173)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>SD</th>
<th>Est. Rel.</th>
<th>Proportion of Variance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Age</td>
<td>Age²</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Boxes</td>
<td>50.8</td>
<td>15.1</td>
<td>—</td>
<td>.113* .003</td>
</tr>
<tr>
<td>Digit Copying</td>
<td>50.9</td>
<td>11.5</td>
<td>—</td>
<td>.199* .004</td>
</tr>
<tr>
<td>Letter Comparison</td>
<td>9.5</td>
<td>3.6</td>
<td>—</td>
<td>.246* .001</td>
</tr>
<tr>
<td>Pattern Comparison</td>
<td>15.6</td>
<td>4.4</td>
<td>—</td>
<td>.335* .002</td>
</tr>
<tr>
<td>Reaction Time-Letters</td>
<td>748</td>
<td>214</td>
<td>.88</td>
<td>.251* .000</td>
</tr>
<tr>
<td>Reaction Time-Symbols</td>
<td>792</td>
<td>229</td>
<td>.91</td>
<td>.256* .000</td>
</tr>
<tr>
<td>MMV</td>
<td>4.98</td>
<td>1.38</td>
<td>.88</td>
<td>.277* .001</td>
</tr>
<tr>
<td>MMS</td>
<td>3.71</td>
<td>1.16</td>
<td>.88</td>
<td>.402* .001</td>
</tr>
<tr>
<td>EMV</td>
<td>79.7</td>
<td>10.6</td>
<td>.80</td>
<td>.087* .001</td>
</tr>
<tr>
<td>EMS</td>
<td>68.5</td>
<td>12.1</td>
<td>.84</td>
<td>.070* .001</td>
</tr>
<tr>
<td>KTV</td>
<td>0.59</td>
<td>0.22</td>
<td>.84</td>
<td>.170* .009</td>
</tr>
<tr>
<td>KTS</td>
<td>3.44</td>
<td>1.37</td>
<td>.91</td>
<td>.142* .015</td>
</tr>
</tbody>
</table>

Notes. MMV = matrix memory-verbal; MMS = matrix memory-spatial; EMV = element memory-verbal; EMS = element memory-spatial; KTV = keeping track-verbal; KTS = keeping track-spatial. Maximum scores in the memory tasks were 7.0 in the MMV and MMS tasks, 100.0 in the EMV and EMS tasks, and 0.0 (no errors) in the KTV and KTS tasks.

*p < .01.
scores. The age effects in these analyses were all significant (i.e., F’s > 10.30), and the condition effects were significant in the matrix memory (F = 31.65) and element memory (F = 27.07) tasks. Only one Age \times Condition interaction was significant, and that involved the contrast of the two matrix memory measures [i.e., F(2,170) = 6.67, MS = 2.14]. Examination of Figure 2 reveals that the interaction was attributable to larger age effects for the verbal measure than for the spatial measure.

It appears from the results described above and from the data summarized in Table 3 and in Figure 2 that the verbal and spatial memory variables differ with respect to the magnitude of their relations with age. However, it is important to note that the rankings of the measures with respect to degree of age-sensitivity differ across types of comparisons. For example, the Age \times Condition interaction on the raw scores suggested that the keeping track–spatial measure was more age-sensitive than the keeping track–verbal measure, but the same type of analysis on the standardized scores revealed no evidence of differential effects on those variables; instead, it suggested that the matrix memory–verbal measure was more age-sensitive than the matrix memory–spatial measure. Furthermore, the age sensitivity of the matrix memory–spatial measure was larger than that of the matrix memory–verbal measure in the amount of variance associated with age (Table 3), but the ranking of the measures was reversed in the comparison in standard deviation units (Figure 2).

The next set of analyses examined the amount of age-related variance in each memory measure that was independent of, or distinct from, the age-related variance in the other measure from the same type of task. Hierarchical regression analyses were used for this purpose by determining the increment in the R² associated with age after control of the variable from the parallel memory task. The residual proportions of age-related variance were .110 (p < .01) for the matrix memory–spatial measure; .017 for the matrix memory–verbal measure; .020 for the element memory–spatial measure; .035 (p < .01) for the element memory–verbal measure; .051 (p < .01) for the keeping track–verbal measure; and .029 (p < .01) for the keeping track–spatial measure.

Although two of the spatial tasks have a significant amount of unique age-related variance, this is also the case for two of the verbal tasks. Therefore, while it is true that not all of the age-related variance in these measures is shared with the measure from the parallel task, this pattern occurs for measures from tasks involving verbal-symbolic information as well as for measures from tasks involving visual-spatial information.

The results from the analyses described thus far provide little support for the hypothesis that age-related deficits are greater in tasks involving spatial information than in those involving verbal information. However, as mentioned earlier, results from single measures may have limited generalizability because of the large specific influences associated with particular methods, materials, and types of assessment. For the next set of analyses, therefore, the variables were aggregated to examine influences at the construct level rather than at the level of single measures.

As with the student data, three speed factors were hypothesized, and a confirmatory factor analysis revealed a good fit of the data to this structure (i.e., \( \chi^2 (df = 6, N = 173) = 13.65; RMR = .029; GFI = .97; AGFI = .91 \)). Correlations between the factors were .44 (SE = .07) between Sensory-Motor Speed and Perceptual Comparison Speed; .44 (SE = .07) between Sensory-Motor Speed and Reaction Time Speed; and .61 (SE = .06) between Perceptual Comparison Speed and Reaction Time Speed.

Separate verbal and spatial factors were hypothesized for the memory variables, and the confirmatory factor analysis revealed that this structure provided a moderate fit to the data (i.e., \( \chi^2 (df = 8, N = 173) = 39.56; RMR = .047; GFI = .94; AGFI = .84 \)). However, the correlation between the verbal and spatial factors was .98 (SE = .04), which was not significantly different from 1.0. There is thus no evidence for the existence of distinct memory factors corresponding to verbal and spatial information in the data from the adult sample.

A complete measurement model was examined with unitary speed and memory latent constructs. Correlated residuals were allowed between the Boxes and Digit Copying measures and between the two reaction time measures to accommodate the existence of distinct speed factors. (The error covariance between the letter comparison and pattern comparison measures was not significantly different from zero and hence was omitted from the model.) This model provided an adequate fit to the data (i.e., \( \chi^2 (df = 51, N = 173) = 114.86; RMR = .053; GFI = .91; AGFI = .86 \), and the correlation between the speed and memory factors was .75 (SE = .05).

Analyses were also conducted to determine whether the same measurement model fit the data from the student sample. Significant reductions in \( \chi^2 \) values were obtained in the two-sample analysis when factor correlations, factor loadings, and error variances were allowed to differ across...
samples, either alone or in combination. It can therefore be inferred that all aspects of the factor structure differ across the two groups. In other words, the relations between factors, the relations of variables to factors, and the residual variances of the variables all differed in the best-fitting models for the student and adult data. Perhaps of greatest interest, the correlation between the speed and memory factors was .38 (SE = .12) in the student data but .75 (SE = .05) in the adult data.

A structural model for the adult data was created by adding age to the model, with paths from age to speed and from age to memory. The fit of this model was adequate (i.e., $\chi^2$ (df = 61, $N = 173$) = 146.56; RMR = .055; GFI = .89; AGFI = .83), and the structural coefficients for the path model are portrayed in Figure 3.

Although the direct path between age and the memory latent construct was −.23, the correlation between age and the memory construct was −.64. Because the total age-related variance on the memory construct was .410 (i.e., −.64$^2$), whereas the amount of age-related variance was only .053 (i.e., −.23$^2$) when speed was considered, these results suggest that a large proportion (i.e., [.410−.053])/.410 × 100 = 87.1%) of the age-related variance on the memory construct was shared with measures of speed.

The proportions of shared age-related variance were also examined for each combination of speed and memory variables. That is, for each variable the proportion of age-related variance shared with every other variable was estimated by determining the $R^2$ for age, determining the increment in $R^2$ for age after control of the other variable, and then subtracting the latter from the former, and dividing the difference by the $R^2$ for age. The resulting values, which are presented in Table 4, reflect the proportion of age-related variance in the target (column) variable that is shared with the controlled (row) variable. The matrix is not symmetric because the amount of age-related variance, and consequently the proportion of age-related variance that is shared, is not necessarily equivalent for the two variables in each pair.

The entries in Table 4 have considerable variability, with a range from .16, for the proportion of reaction time-symbol age-related variance shared with the element memory-verbal measure, to .99, for the proportion of reaction time-symbol age-related variance shared with the reaction time-verbal measure. An analysis of variance revealed that the means for the four quadrants in Table 4 (i.e., top left speed-speed = .667; top right, memory-speed = .584; bottom left, speed-memory = .452; and bottom right, memory-memory = .696) were significantly different, $F(3,128) = 11.09, MS_{\text{e}} = .036$. Bonferroni contrasts indicated that the mean for the age-related variance in the speed variables shared with the memory variables (i.e., .452) was significantly lower than the other values, but that there were no differences between the means for the memory age-related variance shared with other memory variables (i.e., .696) and for the memory age-related variance shared with speed variables (i.e., .584). At least based on these results, therefore, it appears that speed is a more important influence on the age-related variance in the memory measures than vice versa. In fact, the lack of a significant difference between the memory–memory and memory–speed values suggests that, on the average, there is nearly as much overlap of age-related variance between any particular memory variable and any particular speed variable as between two memory variables.

An analysis of variance was also conducted on the data from the memory–memory pairs to determine whether the proportion of shared age-related variance varied according to the type of information in the task. The means for the proportions of age-related variance were: for the spatial memory measures, .677 shared with other spatial memory measures, and .696 shared with verbal memory measures; and for the verbal measures, .738 shared with other verbal memory measures and .680 shared with spatial memory measures. An analysis of variance revealed that there was no significant difference among these conditions (i.e., $F(3,26) = .93, MS_{\text{e}} = .005$).

Estimates of the proportions of shared age-related variance can be converted into a type of correlation coefficient, which has been termed the quasi-partial correlation (Salthouse, 1994b). The quasi-partial correlation reflects the average proportion of age-related variance that is shared between two variables. It is computed by determining the square root of the product of the two proportions for a given pair of variables and then taking the square root of that value. For example, the proportions for the MMV and MMS variables in Table 4 were .93 and .74, which correspond to a quasi-partial correlation of .91. The mean of the 66 quasi-partial correlations resulting from these computations was .75.

Two exploratory factor analyses were next conducted on the matrix of quasi-partial correlations with both one-factor
and two-factor solutions. The results with both solutions are summarized in Table 5, where it can be seen that 77% of the variance is accounted for by a single factor solution and that a second factor accounts for an additional 7.5% of the variance. The correlation between the two factors was .69, and inspection of the rightmost two columns reveals that when two factors are specified, the pattern of loadings for the two factors corresponds to the speed and memory variables.

Two important points should be noted about the data in Table 5. The first is that the communalities are all quite high, with an average of 77% of the age-related variance in these variables accounted for by a single factor and nearly 85% accounted for by two factors. Because there is little residual variance in the variables that is available to be associated with other factors, any more specific factors that might exist could presumably account for relatively small proportions of the age-related variance in these variables.

The second point to note from Table 5 is that the .69 correlation between the two factors indicates that even when a second factor is extracted, it is highly related to the first factor. This finding is consistent with the high correlation (.75) between the speed and memory factors in the measurement model and with the large path coefficient (.59) between these constructs in the structural model portrayed in Figure 3.

**DISCUSSION**

Before discussing the implications of the current results, limitations of the present study should be mentioned. One limitation is that despite the intentions, the measures selected to involve different types of information may not have been completely parallel or equivalent in all respects except for type of information. For example, the keeping track–spatial measure required two-dimensional transformations, whereas the addition and subtraction operations in the keeping track–verbal task were in a single dimension. Differences in the processing requirements may therefore have influenced the age relations in the verbal and spatial versions of each task. Furthermore, although performance in both tasks was assessed in terms of errors, the sensitivity of the distance-from-the-target measure in the spatial task may not have been equivalent to the percentage error measure in the verbal-symbolic task. A second possible limitation of the current study is that the influence of type of information being processed may have been low relative to other influences such as the type, or amount, of required processing.

To the extent that this was the case, the systematic variance attributable to type of information may have been obscured by the variance associated with other factors. These and other as yet unknown characteristics could have contributed to the weak differentiation of verbal and spatial tasks in the present study. Nevertheless, it is important to emphasize that: (a) the memory measures in this study were all quite reliable; (b) the average scores were generally in the middle of the measurement range; and (c) the two memory constructs were moderately differentiated in the data from the student sample. These features, together with the plausi-
bility of the verbal-spatial distinction in the tasks portrayed in Figure 1, suggest that the current study provides a reason-
able, albeit not definitive, test of the hypothesis of differential aging of verbal and spatial information processing.

The first major conclusion from the results of this study is that there is little evidence for selectivity or specificity of age-related effects on verbal and spatial memory tasks. Among the findings leading to this inference are the mixed results from the comparison of individual pairs of measures. Specifically, the pattern with respect to which member of the pair exhibited the larger degree of age-sensitivity was inconsistent across contrasts of original scores, of scores in young adult standard deviation units and of proportions of unique age-related variance. The factor analysis results also fail to support the hypothesis of differential age-related influences on tasks involving visual-spatial compared to verbal-symbolic information. That is, the .98 correlation between the verbal and spatial factors in the confirmatory factor analysis indicates that the measures are not organized into distinct factors in the data from the adult sample. The similar values of shared age-related variance for combinations of memory measures involving the same (i.e., means of .677 and .738) and different (i.e., means of .646 and .680) types of information in Table 4 are also inconsistent with the hypothesis of selective or differential age-related influences.

The second major conclusion from the present study is that a large proportion of the age-related variance in the memory measures is shared with that in the speed measures. This conclusion derives from several sources of evidence obtained from different types of analytical procedures. For example, one relevant result is the .75 correlation between the speed and memory factors in the measurement model fit to the data from the adult sample. Not only is this value high in absolute terms but it is also significantly greater than the correlation (.38) obtained in the model fit to the student data. The larger correlation in the age-heterogeneous sample suggests that the speed and memory constructs may be becoming more similar, or less differentiated, with increased age. A second type of relevant evidence derives from analyses of the proportions of age-related variance shared across combinations of memory and speed variables. An average of over 59% of the age-related variance in the six memory variables and the six speed variables was shared with the other variables (Table 4), and a single factor accounted for 77% of the age-related variance in the 12 variables (Table 5). Finally, the structural model summarized in Figure 3 led to estimates that 87.1% of the age-related variance in the memory factor was shared with the speed factor.

The preceding results all seem to converge on the conclusion that there is considerable commonality in the age-related influences on variables representing memory functioning and variables reflecting speed of processing. Although the direction of the causal linkage is ambiguous on the basis of the results summarized above, two additional results suggest that speed may be the more fundamental construct. First, when the structural model was altered to reverse the direction of the path between speed and memory, it led to estimates that 72.8% of the age-related variance in the speed construct was shared with the memory construct, which is less than the 87.1% of age-related variance in the memory construct that was shared with the speed construct. And second, analyses of the proportions of shared age-related variance in pairs of individual variables revealed that the average amount of age-related variance in the memory variables shared with speed variables (i.e., .584) was significantly greater than the average amount of age-related variance in the speed variables that was shared with memory variables (i.e., .452).

The present results are therefore consistent with previous speculations (e.g., Salthouse, 1992) that the speed measures reflect how quickly many different types of processing operations can be executed. Furthermore, as processing speed slows down with increased age, it may become a central factor influencing the age-related effects in a variety of different cognitive tasks, including those involving different types of information.

In summary, the results of this study do not support the hypothesis that age-related effects are selectively or differentially greater for memory tasks involving spatial information compared to those involving verbal information. Instead, the results suggest that there may be considerable commonalities in the age-related influences across different types of memory measures, as well as across measures reflecting speed of processing. Future research should therefore not only continue to seek evidence for differential or selective age-related influences but in addition should investigate reasons for the common age-related influences that also appear to exist.

ACKNOWLEDGMENTS

This research was supported by NIA grant R37 AG-06826. I would like to acknowledge the valuable assistance of M. Bridges, J. Crawford, A. May, R. Murray, N. Riecke, and B. Smith in recruiting and testing research participants.

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Received June 21, 1994
Accepted September 26, 1994