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Adult Age Differences in Integrative Spatial Ability

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Young and older adults were contrasted in three experiments that involved manipulation of the number of required spatial integration operations (Experiments 1 and 2) and manipulation of the amount of information per operation (Experiment 3). Older adults performed at lower levels of accuracy than did young adults in each experiment. However, the magnitude of the age differences tended to increase with each successive integration operation but was constant across different quantities of relevant information. I interpreted these results as suggesting that one factor responsible for age differences in tests of spatial ability is an age-related reduction in the efficiency of executing operations responsible for the accurate and stable representation of spatial information.

These experiments were designed to investigate why older adults generally perform at lower levels than young adults on mental synthesis or visual integration tasks. For example, Salthouse and Prill (in press) recently reported substantial age differences in favor of young adults on perceptual closure tasks in which the subject is to identify the object represented by an incomplete picture, and they also cited numerous earlier studies with similar results. Tasks resembling jigsaw puzzles in which objects have to be identified from an assemblage of spatially separated pieces have also been used to investigate integration abilities. A common finding from studies with tasks such as these is that performance decreases as age increases from the 20s to the 70s. To illustrate, correlations of −.59 (Botwinick & Storandt, 1974) and −.45 (Mason & Ganzler, 1964) between performance and adult age have been reported on the Hooper Visual Organization Test. Furthermore, results of several large-scale studies involving the Object Assembly subtest from the Wechsler Adult Intelligence Scale-Revised (WAIS-R; Wechsler, 1981), as summarized in Figure 4.8 of Salthouse (1982), revealed that average performance on this test declines about 5% per decade in cross-sectional samples.

Two potential sources of these types of age differences in spatial integration tasks were investigated in the current experiments. One possibility is that the negative relation between age and spatial integration performance is attributable to progressively greater difficulty in executing the required integration operations with increased age. Another possibility is that older adults may perform less well than young adults on spatial integration tasks because of reductions in the capacity of some type of spatial-information storage system. Although not necessarily mutually exclusive, these two alternatives are of considerable theoretical interest because they represent conceptually distinct forms of complexity, and it is often maintained that the magnitude of age differences in cognitive tasks increases with task complexity (e.g., see Salthouse, 1985, for a review of this topic). A finding that aging is selectively sensitive to one of these manipulations but not to the other would therefore suggest that theoretical interpretations of age differences in cognition should incorporate a distinction between complexity as mediated by the number of relevant operations and complexity influenced by the amount of information associated with each operation. One conceivable way of representing this difference is that the former reflects the activity of dynamic factors responsible for the quality or quantity of processing, whereas the latter is related to the static or structural capacity of a spatial memory system.

A mental synthesis task was used in the current studies for the following reasons: (a) Prior research has demonstrated that synthesis tasks are easily amenable to experimental investigation (e.g., Palmer, 1977; Poltrock & Brown, 1984; Thompson & Klatzky, 1978), (b) substantial adult age differences have been reported with this type of task (Ludwig, 1982), and (c) it seemed to involve the same type of integration ability required in psychometric tests of spatial ability such as those I have cited. The task consists of the presentation of successive frames of line segments from a multisegment figure, followed either by a complete comparison figure or by instructions to reproduce the synthesized figure. In the verification version of the procedure used here, the subject is instructed to decide whether the synthesized or integrated composite is identical to the comparison figure.

Experiments 1 and 2 manipulated the number of frames containing to-be-integrated figure segments in order to determine whether older adults were more affected than were young adults by increasing the number of synthesis or integration operations that must be performed. An outcome of this type would suggest that one of the determinants of the poorer performance of older adults on synthesis tasks is that they are less efficient than young adults in the process of integrating discrete pieces of information. Sample problems from the four conditions in the experiments are illustrated in Figure 1A. Notice that all of the complete figures contain 12 line segments, but that in different con-

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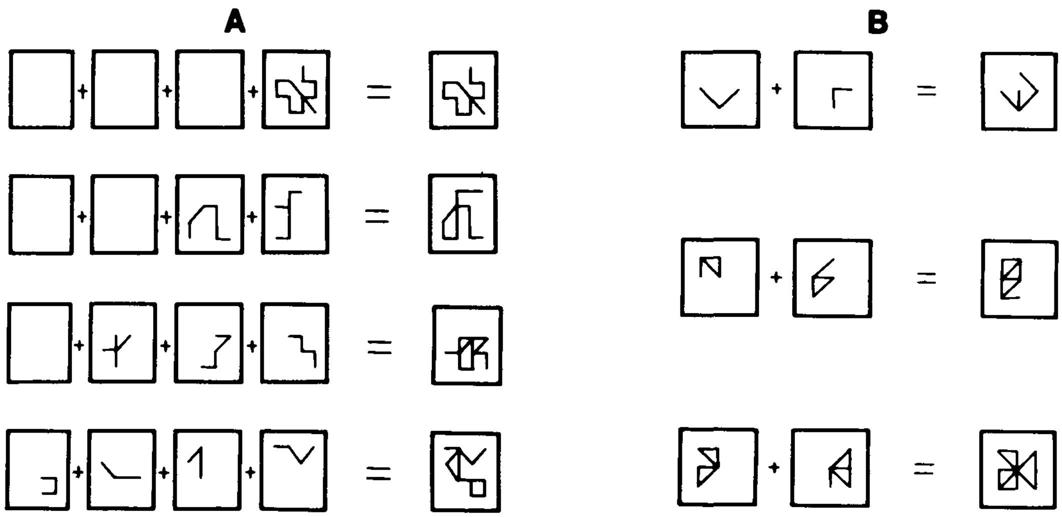

Figure 1. Illustration of synthesis problems in the three experiments. (Section A = Experiments 1 and 2; Section B = Experiment 3.)

ditions these segments were distributed across one, two, three, or four to-be-integrated frames.

In Experiment 3, the number of frames was held constant at two, and the number of line segments in the total figure was manipulated. However, because it seemed reasonable to distinguish between the amount of information that must be retained in memory and the amount of information to which the remembered information must be added, the distribution of line segments to the first and second frames was systematically varied. Either 2, 4, or 6 line segments were presented in each frame, with the orthogonal combination resulting in nine conditions, with from 4 to 12 segments in the composite figure. Examples of problems in the 2–2, 4–4, and 6–6 conditions are illustrated in Figure 1B.

Because the frames in Experiment 3 were presented successively and the first was removed before the second was displayed, it was possible to determine whether the magnitude of age differences in performance was influenced by the amount of information that must be preserved from the first to the second frame or by the amount of information to which the information from memory must be assimilated. If the former is the case then the age differences in performance should increase with the number of segments in the first frame, and if the latter is the case then the age differences should increase with the number of segments in the second frame. On the other hand, if it is simply the total amount of information that is critical in determining the magnitude of the age differences, then both the number of segments in Frame 1 and the number of segments in Frame 2 should have significant interactions with age, such that the difference between young and older adults increases with the number of segments in the composite figure.

To summarize, the three experiments of this project were designed to determine whether age differences in integration or synthesis tasks are related to difficulties in executing the required operations or to problems in handling the relevant quantities of information. Experiments 1 and 2 consisted of a manipulation of the number of required integration operations, with the interaction between age and the number of relevant operations expected to indicate whether older adults are affected more than young adults by the performance of additional synthesis operations. Experiment 3 involved manipulating the number of line segments in each of the to-be-integrated frames, with examination of the interactions of age and number of line segments in each frame expected to be informative about whether older adults are affected more than young adults by variations in the amount of information that must be integrated.

Experiments 1 and 2

The first two experiments—which were nearly identical and, hence, are described together—were conducted as part of a larger project (Salthouse, in press). Because a goal of that project involved analyses of patterns of correlations, rather large samples of young and older adults were employed in order to provide stable estimates of the correlations.

Method

Subjects: Experiment 1. Sixty-two women and 38 men[1] between the ages of 18 and 25 years (M = 19.1 years), and 63 women and 37 men between the ages of 57 and 67 (M = 62.4), participated individually in a single experimental session of approximately 1.5 hr. Self-reported health status (1 = *excellent*, 5 = *poor*) averaged 1.2 for the young adults and 2.0 for the older adults; 96% of the young adults and 94% of the older adults reported themselves to be in average or better-than-average health. The range of education in the young group was from 12 to 15 years (M = 12.4), and that in the older group, from 8 to 22 years (M = 14.2 years). Scores on the Digit Symbol subtest from the WAIS-R ranged from 49 to 90 (M = 69.8) in the young sample, and from 12 to 68 (M = 45.0) in the older sample. In all respects, these data indicate that the

[1] Sex differences were not statistically significant (i.e., all $ps > .10$) with any of the dependent measures in Experiments 1, 2, or 3, and thus all analyses are collapsed across sex.

subjects are fairly typical of those who participated in previous studies of cognitive aging.

Experiment 2. A total of 50 women and 50 men between the ages of 17 and 26 years (M = 18.9 years), and 20 women and 20 men between the ages of 55 and 75 years (M = 63.6 years), participated individually in a single experimental session of approximately 1.5 hr. Self-reported health status (1 = *excellent*, 5 = *poor*) averaged 1.4 for the young adults and 1.9 for the older adults; 98% of the young adults and 95% of the older adults reported themselves to be in average or better-than-average health. The range of education in the young group was from 11 to 17 years (M = 12.4 years), and that in the older group, from 6 to 20 years (M = 13.3 years). Digit Symbol scores ranged from 48 to 97 (M = 73.7) for young adults, and from 17 to 64 (M = 48.6) for older adults. These data indicate that the subject populations were comparable to those in Experiment 1, and were representative of those used in other studies of cognitive aging.

Procedure. All of the subjects were tested individually, with the problems—in a format like that illustrated in Figure 1a—displayed in test booklets and the answers provided orally. Stimulus configurations consisted of 12 connected line segments joining dots in an imaginary 4 × 4 matrix. Each configuration was decomposable into parts consisting of 3, 4, or 6 connected line segments. A total of 64 problems were distributed across 16 pages, with 4 problems containing the same number of to-be-integrated frames on each page. The test booklet started with instructions about the task and several examples of each type of problem, followed by successive pages increasing, decreasing, increasing, and finally decreasing with respect to the number of to-be-integrated frames in the problem. One half of the problems in each number-of-frames condition should have been answered *yes* because they involved similar configurations on the left and right sides of an equal sign, and one half should have been answered *no* because they consisted of mismatching configurations on the two sides of the equal sign. When the configurations did not match, they differed in the position of a single line segment randomly selected from any of the successively presented frames.

Subjects were instructed to respond accurately and as soon as they knew the answer to the problem, but they were allowed as much time as necessary to respond. A stopwatch was used to record the time to answer all four problems on a given page; this value was then divided by 4 to obtain a measure of average time per problem on that page.

The procedure in Experiment 2 was very similar, except that an additional set of trials was administered and a spatial memory test was presented to all of the subjects. Analyses of the second set of trials revealed no interactions with practice and thus only the data from the first set are discussed (see Salthouse, in press, for further details about the practice effects).

The spatial memory task was similar to that described by Salthouse (1974, 1975), and consisted of a 5 × 5 matrix of 25 letters, with seven targets printed in reverse (i.e., white on a black background instead of black on a white background). The task for the subject was to view the matrix for 3 s and then attempt to recall the locations of the target elements. The locations were recalled by marking cells in a blank 5 × 5 matrix, and the subject was instructed to guess if necessary to produce seven responses on each trial. Four trials were presented at the beginning of the session, with the initial, unscored trial serving as practice, and three trials were presented at the end of the session.

Results and Discussion

The percentages of correct decisions for each number-of-frames condition in the two age groups and the two experiments are displayed in Figure 2. The most important aspect of these data is that performance deteriorated with an increase in the number of synthesis operations required to produce the composite figure, and that the magnitude of this deterioration was greater for older adults than for young adults. The interaction of Age × Number of Frames was significant ($p < .05$) in both Experiment 1, $F(3, 594) = 5.69$, and Experiment 2, $F(3, 414) = 3.18$, as were the main effects of age, $F(1, 198) = 37.52$, for Experiment 1, and $F(1, 138) = 15.64$, for Experiment 2; and number of frames, $F(3, 594) = 101.52$, for Experiment 1, and $F(3, 414) = 81.01$, for Experiment 2. Analyses of variance (ANOVAS) were also conducted on the accuracy data involving at least one integration operation (i.e., 2, 3, or 4 frames). The Age × Number of Frames interaction was still significant in Experiment 1, $F(2, 396) = 3.88$, $p < .05$, but was no longer significant in Experiment 2, $F(2, 276) = 1.06$.

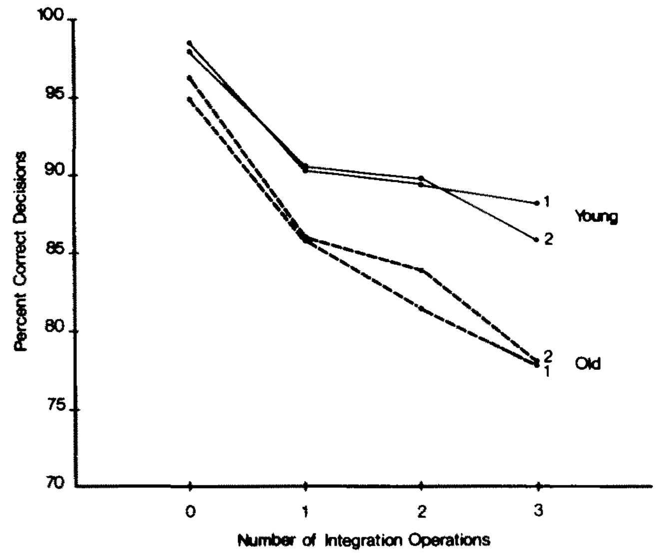

Figure 2. Mean percentage of correct synthesis decisions for young and older adults as a function of number of to-be-integrated stimulus frames in the problem: Experiments 1 and 2.

Because effectiveness of performance is reflected in both the accuracy and the speed of one's decisions, similar analyses were conducted on the measure of decision latency. Trends parallel to those with the accuracy measure were evident in this measure, although with the decision latency variable, the Age × Number of Frames interaction was highly significant in both experiments even when the data from the one-frame condition were excluded from the analysis. The mean times per problem are displayed in Table 1, and it can be seen that the difference between young and older adults increased monotonically with the number of to-be-integrated frames. The Age × Number of Frames interactions (all $ps < .01$) were 10.16 across all frame conditions in Experiment 1; 9.32 across 2, 3, and 4 frames in Experiment 1; 7.63 across all frames in Experiment 2; and 7.57 across 2, 3, and 4 frames in Experiment 2.

The true magnitude of the interaction effects is difficult to determine because the existence of similar patterns in both the accuracy and latency variables suggests that the effects would almost certainly have been larger in either variable had it been possible to control the level of the other variable. It nevertheless seems clear that as the number of required integration operations increases, older adults suffer greater performance impairments than do young adults, with those impairments mani-

Table 1
Latency of Synthesis Decisions (in Seconds) in Experiments 1 and 2 as a Function of Number of Required Integration Operations

Condition	No. of integration operations 0	1	2	3
Experiment 1				
Young	3.31	8.31	12.00	13.79
Old	5.60	11.34	15.81	19.20
Difference	2.29	3.03	3.81	5.41
Experiment 2				
Young	2.76	7.29	10.10	11.81
Old	5.48	10.62	13.98	16.76
Difference	2.72	3.33	3.88	4.95

fested in terms of reduced accuracy or increased decision time, or both.

Performance on the spatial memory test in Experiment 2 was summarized in terms of the mean number of target positions correctly reproduced across the last six trials. These values averaged 4.94 (SD = 0.91) for young adults, and 3.81 (SD = 0.69) for older adults, a difference that was highly significant, $t(138) = 7.06, p < .01$.

Experiment 3

The results of Experiments 1 and 2 demonstrate that the greater the number of required integration operations, the larger the magnitude of the age differences in synthesis tasks. However, because the number of segments in the composite figure was held constant at 12, the number of integration operations was confounded with the amount of information that must be preserved in memory. That is, when there were no integration operations required, no intermediate memory representation was necessary, but as the number of operations increased from 1 to 2 to 3, the number of segments in the constructed representation at the time of the last operation also increased from 6 to 8 to 9. It is therefore possible that the pattern exhibited in Figure 2 is attributable to an increase in the informational requirements of the constructed representation and not simply to additional integration operations.

The primary goal of Experiment 3 was to investigate this hypothesis by holding the number of required integration operations constant and determining whether the magnitude of age differences in synthesis performance was influenced by the amount of information contained in the first and second frames that had to be integrated to produce the composite figure. A microcomputer was used to allow precise control of the timing of each successive frame.

Table 2
Synthesis Decision Accuracy in Percentage Correct and Latency (in Seconds) as a Function of Number of Segments in Frames 1 and 2 in Experiment 3

No. of segments in Frame 2	No. of segments in Frame 1: 2	4	6	*M*: Young	Old
2					
Young					
% correct	91.3	90.8	82.9	88.3	
Latency	2.35	2.70	2.77	2.61	
Old					
% correct	80.4	77.5	69.2		75.7
Latency	3.60	4.00	3.85		3.82
4					
Young					
% correct	86.3	85.4	84.2	85.3	
Latency	2.42	2.98	2.96	2.79	
Old					
% correct	74.2	71.7	61.7		69.2
Latency	4.31	3.95	4.26		4.17
6					
Young					
% correct	87.1	76.3	70.0	77.8	
Latency	3.33	3.20	3.82	3.45	
Old					
% correct	72.5	60.8	59.2		64.2
Latency	3.89	3.92	4.47		4.09
M					
Young					
% correct	88.2	84.2	79.0		
Latency	2.70	2.96	3.18		
Old					
% correct	75.7	70.0	63.4		
Latency	3.93	3.96	4.19		

Method

Subjects. Thirteen women and 7 men between the ages of 18 and 26 years (M = 19.6 years), and 13 women and 7 men between the ages of 59 and 75 years (M = 66.7 years), participated individually in an experimental session lasting approximately 1 hr. Self-reported health status (1 = *excellent*, 5 = *poor*) averaged 1.5 for the young adults and 1.9 for the older adults; 100% of the young adults and 95% of the older adults reported themselves to be in average or better-than-average health. The range of education in the young group was from 11 to 18 years (M = 13.2 years), and that in the older group was from 8 to 22 years (M = 15.7 years). Digit Symbol scores ranged from 47 to 85 (M = 67.8) for young adults, and from 26 to 60 (M = 47.6) for older adults.

Procedure. All of the subjects performed the Spatial Memory task from the previous experiment and a computerized version of the Mental Synthesis task. The Spatial Memory task was identical to that used in Experiment 2, except that it was presented in a single administration of eight trials at the beginning of the session; the initial two trials were considered practice and were not analyzed.

The Mental Synthesis task consisted of three successively presented boxes (of approximately 6 cm per side). The first box contained the line segments in the first frame, the second contained the line segments in the second frame, and the third contained a composite against which the subjects were to compare their synthesized figure. The frames were each presented for 1 s, and were immediately followed by a screen-erasing solid mask. The interval between successive presentations was 1.5 s, and the comparison figure remained visible until the subject made a response (depression of the Y key on the computer keyboard for a match and the N key for a mismatch). Accuracy was emphasized more than speed, but subjects were encouraged to respond as quickly as was consistent with high accuracy. Decision latency was measured by the computer to a precision of 10 ms.

The major within-subject independent variables in this experiment were the number of segments presented in the first and second frames of each problem. The levels of each variable were 2, 4, and 6, resulting in a total of nine experimental conditions (i.e., the orthogonal combination of three possible values for the first frame and three possible values for the second frame). An illustration of the stimuli for the 2–2, 4–4, and 6–6 conditions is displayed in Figure 1B. Three blocks of 36 trials each were constructed, in which 4 different trials represented each of the nine experimental conditions.

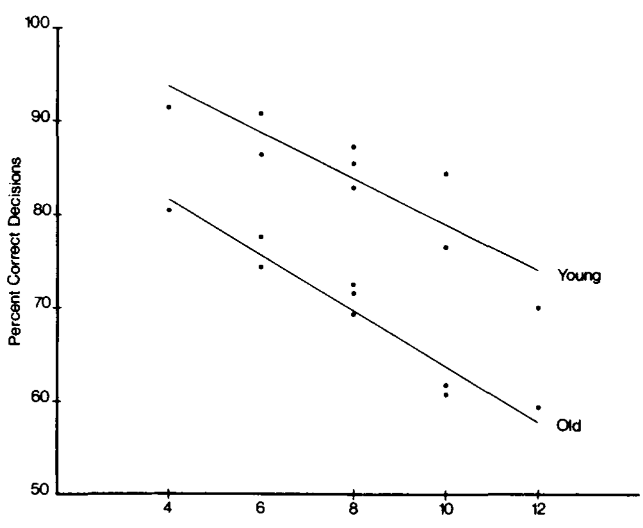

Figure 3. Mean percentage of correct synthesis decisions for young and older adults as a function of the number of line segments in the composite figure: Experiment 3.

Table 3
Correlations Between Synthesis Accuracy and Measures of Speed and Memory Across Conditions in Experiments 1 and 2

	No. of integration operations			
Condition	0	1	2	3
Digit Symbol				
Young				
Experiment 1	−.03	−.10	−.01	.03
Experiment 2	.19	−.09	.04	.04
Old				
Experiment 1	.07	−.02	−.09	−.03
Experiment 2	.44*	.67*	.51*	.70*
Spatial Memory (Experiment 2)				
Young	.26*	.07	.16	.28*
Old	.27	.43*	.42*	.65*

* $p < .01$.

Results and Discussion

The mean percentages of correct decisions and decision latencies for young and older adults across the nine conditions in Experiment 3 are displayed in Table 2. A 2 × 3 × 3 (Age × Number of Frame 1 Segments × Number of Frame 2 Segments) ANOVA on the accuracy variable revealed the following significant ($p < .01$) effects: age, $F(1, 38) = 48.75$; number of frame 1 segments, $F(2, 76) = 26.95$; and number of frame 2 segments, $F(2, 76) = 38.16$. The Frame 1 × Frame 2 interaction was also significant, $F(4, 152) = 2.68$, $p < .05$, but none of the interactions with age were significant; that is, all Fs < 1.3, $p > .25$, indicating that it was impossible to identify different patterns of effects among young and older adults.

Nearly identical results were obtained in analyses with the latency measure, including the absence of significant interactions of Age × Number of Frame 2 Segments, $F(2, 76) < 1.0$, and Age × Number of Frame 1 Segments × Number of Frame 2 Segments, $F(4, 152) < 1.85$. The Age × Number of Frame 1 Segments interaction was significant, $F(2, 76) = 9.11$, $p < .01$, but the data in Table 2 indicate that this is attributable to the age difference decreasing, rather than increasing, in magnitude as the amount of information in the first frame increased. The reasons for this pattern are not obvious, but because it is in the opposite direction from that expected if older adults experience greater impairments than young adults as the information load increases, it does not jeopardize (and actually strengthens) the conclusion that older adults experience no greater difficulty than do young adults as the amount of information increases.

An alternative means of representing the accuracy data in Table 2 is in terms of a plot of accuracy of synthesis decisions as a function of the total number of figure segments in each condition. Figure 3 illustrates the mean data from each age group in this format. Notice that the two groups exhibit similar accuracy reductions with additional figural segments, but that the older adults had uniformly lower levels of accuracy than

Table 4
Correlations Between Synthesis Accuracy and Measures of Speed and Memory Across Conditions in Experiment 3

	Total no. of segments in composite figure								
Condition	4 (2–2)	6 (2–4)	6 (4–2)	8 (2–6)	8 (4–4)	8 (6–2)	10 (4–6)	10 (6–4)	12 (6–6)
Digit Symbol									
Young	−.17	−.27	−.49	.01	−.04	−.07	−.18	.27	.02
Old	.35	.01	.25	.45	.03	.11	.08	.07	−.05
Spatial Memory									
Young	.05	.01	−.18	.11	.42	.12	.03	.40	.56
Old	.14	.09	.31	.29	.35	−.15	.10	.02	.17

the young adults. These trends were statistically evaluated by conducting t tests on the regression parameters derived from each individual subject's data. The age difference in the slope parameter was far from significant, $t(38) = 1.02$, $p > .30$, but the intercept of young adults was slightly greater than that of older adults, $t(38) = 2.02$, $p < .06$. However, the data from several subjects (4 young, 3 older) had very poor fits to the linear equations (i.e., $r^2 < .10$), and thus another analysis was conducted excluding the data from these subjects. Results from the remaining subjects revealed significantly greater intercepts for young adults, $t(31) = 2.43$, $p < .05$, but no significant difference in the magnitude of the slope parameter, $t(31) = 1.32$, $p > .15$. Score on the spatial memory test averaged 4.68 ($SD = 0.76$) for young adults, and 3.76 ($SD = 0.54$) for older adults, $t(38) = 4.40$, $p < .01$.

Because the condition with six segments in both Frames 1 and 2 in Experiment 3 was structurally equivalent to the condition with one integration operation in Experiments 1 and 2, it was possible to use these data to examine the effects of simultaneous (Experiments 1 and 2) versus successive (Experiment 3) presentation of the to-be-integrated stimuli. Accuracy was considerably lower with successive presentation. Mean percentages correct with simultaneous presentation were 90.2, 90.4, 85.6, and 85.7 for Experiment 1, young; Experiment 2, young; Experiment 1, old; and Experiment 2, old, samples, respectively, and only 70.0 for the young subjects and 59.2 for the older subjects in Experiment 3. Successive presentation resulted in much faster decisions, however, as the mean seconds per problem were 8.31, 7.29, 11.34, and 10.62 for the Experiment 1, young; Experiment 2, young; Experiment 1, old; and Experiment 2, old samples, respectively, but only 3.82 for the young subjects and 4.47 for the older subjects in Experiment 3. Unfortunately, because for both young and older groups, accuracy was lower but speed was faster in the successive compared with the simultaneous condition, it was impossible to determine whether one age group was affected more than another by a particular manner of stimulus presentation.

General Discussion

The major results of these experiments are that the age differences in synthesis accuracy or time (or both) tend to increase when additional integration operations are required, but remain relatively constant across variations in the amount of relevant information. An apparent implication of these findings is that aging is associated with a reduction in the efficiency or effectiveness of processing operations, but does not alter the quantity of information that can be handled in each operation.

One means of interpreting this pattern of results is in terms of the building of an integrative structure relating figural segments to one another in an internal representation. Each synthesis operation can be considered to result in a structure at a progressively higher level of abstraction, with very few restrictions on the number of segments that can be integrated within a given level. Reductions in synthesis accuracy (or increases in synthesis time) associated with additional integration operations could be attributable to imprecision or instability in the representational structure, whereas lower accuracy (longer time) with a greater number of to-be-integrated segments could simply be due to a lower probability of recognizing specific figural segments as a finite amount of neural excitation is distributed among more relevant elements. From this perspective, therefore, aging might be viewed as leading to the weakening of the quality or durability of the internal representations but having relatively little effect on the informational capacity of each representational unit.

An advantage of this conceptualization of the synthesis task is that it is consistent with an interpretation recently advanced for age differences observed in a series-completion reasoning task (Salthouse & Prill, 1987). The discovery that age differences increased as the abstractness of the relation among problem elements increased, together with a finding that very similar processing strategies were apparently used by both groups, led to the inference that older adults constructed flimsier and less reliable representational structures.

The question of why the processing of older adults is shallower and results in lower quality or less stable representations was also addressed in the earlier study. Specifically, it was suggested that increased age might be associated with a reduction in a critical processing resource such as energy (attentional capacity), space (working-memory capacity), or time (rate of processing). A lack of a significant correlation between reasoning performance and an index of working-memory capacity, and the absence of a means of assessing attentional capacity led to little support for the first two interpretations. On the other hand, the finding that older adults were slower than young adults on all available measures was considered consistent with the view that age-associated reductions in a resource related to time or speed contributed to the age differences in reasoning performance.

The results of the present studies appear generally consistent with those of the Salthouse and Prill (1987) experiments. As in the reasoning experiments, older adults were not only less accurate than young adults, but were consistently slower (e.g., see Tables 1 and 2). Moreover, the discovery that the older adults were affected no more than were young adults by increasing the amount of relevant information, suggests that static or structural memory factors are not the major determinant of age differences in spatial integrative ability.

An additional investigation of the processing resources perspective was conducted by using the Digit Symbol substitution and Spatial Memory measures as indices of processing resources conceptualized in terms of time or speed, and space or memory. The reasoning was as follows: If performance variations across individuals within each age group are also mediated by varying quantities of an essential processing resource, one should expect the correlations between an index of resource quantity and measures of performance to increase as the demands for those resources increase. In other words, the relation between resource quantity and measures of performance should become more pronounced as the task becomes more complex or difficult, and presumably requires more processing resources for its successful completion. Data relevant to this expectation are summarized in Tables 3 and 4.

The results shown in Tables 3 and 4 indicate that, contrary to the predictions I have outlined, the correlations between performance accuracy and the measures that serve as the indices of the speed and memory resources did not vary systematically across conditions in which the demands for processing resources presumably increased. A trend of this type does seem to be evident in the older subjects of Experiment 2, with both resource indices, but it is apparently not reliable because it did not occur in any of the other comparisons. Failure of the correlation predictions may be due either to invalid measures of processing resources or to a substantially weaker contribution of resource quantity to performance differences across individuals within the same age group than to performance differences across individuals from different age groups; but under any circumstances these results indicate important limitations of the processing resource interpretation of cognitive aging phenomena.

It is, obviously, still too early to conclude that processing resources related to the rate of information processing is a major factor in the age-related differences observed in most cognitive tasks, and the present data provide no support for a role of processing resources in individual differences within age groups. Nevertheless, there is a growing body of evidence that the quantity of some type of processing resource is diminished with increasing age, and that this resource reduction contributes to many cognitive age differences (cf. Salthouse, in press). Moreover, the available data seem to implicate temporal resources at least as much as resources related to energy (attention) or space (working memory capacity).

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