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Effects of Increased Processing Demands on Age Differences in Working Memory

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Three studies investigated (a) the plausibility of the claim that increasing the processing demands in a memory task contributes to greater involvement of a central processor and (b) the effects of altering reliance on the central processor on the magnitude of age-related differences in working-memory tasks. In the first study, young adults performed versions of 2 tasks presumed to vary in the degree of reliance on the central processor. In the second and third studies, young and older adults performed versions of a computation-span task that were assumed to vary along a rough continuum of the amount of required processing. The results indicated that although a central processor appears to be involved when working-memory tasks require simultaneous storage and processing of information, age-related differences in working memory seem to be determined at least as much by differences in the capacity of storage as by differences in the efficiency of processing.

Adult age differences in measures of cognitive functioning are often attributed to age-related limitations in working memory (Hartley, 1986; Light & Anderson, 1985; Stine & Wingfield, 1987; Stine, Wingfield, & Poon, 1986; Welford, 1958). However, there is still no consensus about the nature of working memory, or more specifically, the aspect of working memory that is most affected by age. Working memory is usually defined as involving both storage and processing, and most proposed measures of working memory require the preservation of some information while concurrently processing the same or other information (e.g., the reading-span task of Daneman & Carpenter, 1980, and the counting-span task of Case, Kurland, & Goldberg, 1982). It is therefore possible that age-related differences in working memory originate because of age differences in the capacity of storage, age differences in the efficiency of processing, or age differences in both storage and processing. A primary purpose of this research was to determine which of these alternatives provides the most accurate characterization of adult age differences in working memory.

The contribution of different factors to the age differences in working memory was investigated by comparing spans of young and older adults when different amounts of simultaneous processing were required. However, this strategy implicitly assumes that the processing manipulation exerts its influence by increasing demands on a central processor. That is, according to current conceptions of working memory, adding a requirement of simultaneous processing to a memory-span task is presumed to make performance on that task more dependent on the efficiency of a single central processor. Therefore, we conducted an initial study to examine the validity of this important assumption.

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Study 1

The rationale underlying this control or validation study can be understood in the context of an influential model of working memory proposed by Baddeley (1986). He hypothesized that there are at least two distinct storage regions, concerned with auditory–verbal information and visual–spatial information, and a single central executive system that is responsible for the processing and manipulation of information. On the basis of Baddeley's model, it therefore seems reasonable to infer that when the memory tasks involve primarily storage, performance will depend on more or less independent peripheral components. However, as the memory task involves progressively more concurrent processing, performance should become increasingly dependent on the common central executive system to process or manipulate the information to be remembered. One means of determining whether increases in the amount of required processing alter demands on a central processor therefore consists of examining correlations between measures of performance on tasks with different types of information. If simultaneous processing increases the involvement of a common processor, then the correlations between the span measures should be higher when such processing is required than when it is not.

In contradiction to Baddeley's (1986) model, Daneman and Tardif (1987) have recently suggested that working memory is domain specific, not based on a common central processor.

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The primary evidence for their conclusion was a finding that only a measure of verbal working memory, and neither a measure of mathematical working memory nor a measure of spatial working memory, was a significant predictor of reading comprehension. No information about the respective reliabilities of the various measures was presented, however, so it is impossible to determine whether the lower levels of prediction were attributable to the operation of domain-independent memory systems or to varying degrees of measurement reliability that allowed differential levels of correlations with other variables. Therefore, our theoretical assumptions and predictions are based on Baddeley's model of working memory as outlined earlier.

To examine the possible involvement of a common central processor in working memory, we developed memory tasks that have similar formats but that involve different types of information (verbal–symbolic or visual–spatial). Alternative versions of the tasks were postulated to yield measures of memory involving primarily the peripheral components (storage) or else the peripheral components and the central processor (storage and processing). These two measures were estimated by a simple memory-span task that indicates the number of items that can be accurately remembered without any concurrent processing, and a working-memory-span task that indicates the number of items that can be accurately remembered while simultaneously carrying out specified processing.

In the storage-plus-processing memory task involving verbal–symbolic information, participants were presented a series of arithmetic problems in which they had to respond with the correct solution while remembering the last number in each problem. A typical series of problems is illustrated in Figure 1 (left panel). The arithmetic problems appeared one at a time on a computer screen, and the participants had to type the correct answer to the problem while simultaneously trying to remember the second number of each equation. After a series of problems was presented, the participants were asked to recall the target (second) numbers in the order in which they were presented.

In the visual–spatial task, the participants were presented a series of problems in which they had to use a mouse interfaced to a microcomputer to connect *X*s that appeared within two squares of a 4 × 4 matrix while simultaneously remembering the location of a different line segment connecting two squares in the matrix. To prevent participants from attempting to encode the location of the lines in the matrix with verbal descriptions such as "second row, third column," the squares in the matrix were not visible unless they were displayed as endpoints of the to-be-remembered line or as the to-be-connected locations in the processing phase. A typical series of problems is illustrated in Figure 1 (right panel). Because the tasks just described were assumed to assess memory during processing, they were designated *VMP* (for verbal memory and processing) and *SMP* (for spatial memory and processing).

The second version of each task was a storage or memory-only condition of the previous span tasks (*VM* for verbal memory and *SM* for spatial memory) in that the participants did not have to process any information while trying to remember the stimuli. Although the displays were identical to those in the VMP and SMP tasks, the participants were told to ignore the irrelevant information (i.e., the arithmetic problems or the squares with *X*s); they were scored only on the number of items correctly recalled in the recall phase.

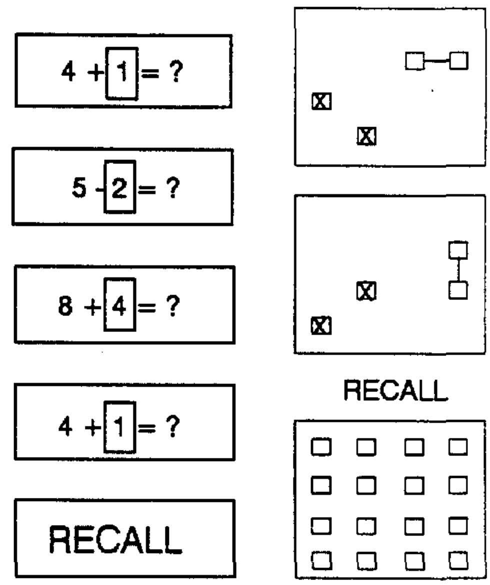

Figure 1. Left: Example of typical problem from the verbal memory and processing task. Right: Example of typical problem from the spatial memory and processing task.

Only young adults participated in this initial study because the predictions of primary interest were independent of age. That is, the major goal of Study 1 was theoretical, in that it concerned the validity of the assumption that greater processing requirements lead to more involvement of a central processor. Furthermore, age-related differences have already been established in the two storage-plus-processing tasks (i.e., Salthouse, Babcock, Skovronek, Mitchell, & Palmon, 1990, for the SMP task; and Salthouse, 1988; Salthouse & Mitchell, 1989; Salthouse, Mitchell, Skovronek, & Babcock, 1989; and Salthouse & Prill, 1987, for the VMP task).

Method

Participants

A total of 80 students (41 men and 39 women, mean age = 19.7 years) at the Georgia Institute of Technology participated in two slightly different studies. Forty-two of the students received extra credit in psychology classes for participation in Study 1A, and 38 received either extra credit or $10 for participation in Study 1B.

Procedure

Study 1A. Students participating in Study 1A performed all of the tasks in one 90-min session. Participants began the session with practice in maneuvering a mouse-controlled cursor through a maze on the computer screen until they felt comfortable with the use of the mouse.

Because the primary comparisons of interest were between-subjects correlations, all participants received the tasks in the same order to avoid a confounding of subject and task order. The verbal–symbolic span tasks were performed first (VM followed by VMP) and were immediately followed by the visual–spatial span tasks (SM and SMP). To allow assessment of the reliability of the measures, each of the tasks was performed again with the order of the tasks reversed.

In the assessment of spans, two separate sequences (one starting with two problems for the verbal task and starting with one problem for the spatial task, the other starting with nine problems for the verbal task and starting with four problems for the spatial task) were presented to each participant in a double-random-staircase psychophysical procedure. The number of problems presented on a given trial was increased by 1 if the participant had responded correctly on the previous trial in that sequence and was decreased by 1 if the participant had responded incorrectly on the previous trial in the sequence. If all of the arithmetic problems were not answered correctly, the number of problems presented in the next trial was not changed. The estimate of the individual's span was determined by the average of the final value of two sequences that terminated when the number of items presented did not change by more than 2 across four successive trials (see Salthouse et al., 1989, for a detailed description of this procedure). The trials in all tasks were self-paced.

Study 1B. Study 1B consisted of two 90-min sessions completed within approximately 1 week of each other. In the first session, all the verbal–symbolic tasks were administered, and in the second session, all the visual–spatial tasks were presented. Because initial analyses revealed substantial practice effects in Study 1A, especially with the spatial material, participants in Study 1B were allowed to practice the storage-plus-processing memory version of each of the tasks for 15 min before performing the respective series of verbal or spatial tasks. After the practice session, each participant was timed on his or her ability to perform the processing (i.e., arithmetic or line creation), without testing for any simultaneous storage. These durations were then multiplied by a constant (2.0) and were used as the maximum allowable duration in each series of tasks. (The constant 2.0 was arbitrary, but we assumed that it was small enough to encourage participants to perform the task as rapidly as possible but large enough to allow most participants to both store and process the information.)

In the first session, the participants performed the VM and then the VMP task. The tasks were then performed again in the reverse order to allow an assessment of the reliability of the measures. In the second session of Study 1B, the participants began by practice in maneuvering the mouse through the maze as described in Study 1A. They then practiced the SMP task for 15 min. Next, participants performed the visual–spatial tasks in the same order as the verbal–symbolic tasks were performed in the first session: SM followed by SMP. The tasks were then performed again in the reverse order. Spans were assessed with the same procedures as those used in Study 1A for both the verbal and spatial tasks.

Results and Discussion

The primary measures of performance in Study 1 were span estimates on tasks hypothesized to involve only the peripheral components (VM and SM) and span estimates for tasks postulated to involve both the peripheral components and the central processor (VMP and SMP). The correlations in Studies 1A and 1B were consistent with the expectation that the tasks involving more processing would have a higher correlation with one another than would the tasks involving little processing. In both studies, this finding was represented by a significant ($p < .05$) correlation between the storage-plus-processing measures (r[VMP − SMP] = .33 in Study 1A and .47 in Study 1B) and a nonsignificant correlation between the storage-only measures (r[VM − SM] = .11 in Study 1A and .16 in Study 1B). However, because the sample sizes were small in both studies, and because the correlation matrices appeared similar, we decided to determine whether the two samples could be pooled to provide more statistical power.

Table 1
Correlation Matrix for Storage Measures Pooled Across Studies 1A and 1B

Measure	1	2	3	4
1. Verbal memory	(.53*)			
2. Verbal memory and processing	.36*	(.67*)		
3. Spatial memory	.10	.23*	(.55*)	
4. Spatial memory and processing	.32*	.40*	.57*	(.61*)
M	6.78	5.39	4.22	3.64
SD	(0.89)	(1.26)	(0.92)	(0.94)

Note. In assessing all reliabilities (shown in parentheses), the Spearman-Brown boosted correlations were used because the between-measures correlations were based on the average scores.
* $p < .05$.

First, t tests on the means of the span measures from both studies revealed only one significant difference, between the VM measures in the verbal tasks, 6.60 versus 6.99, $t(78) = -1.88$, $p < .05$. More important, Box's (1949) M test revealed that there was no evidence that the covariance matrices were not homogeneous, $\chi^2(21, N = 80) = 20.59$, $p > .05$. These analyses provided no reason to believe that the covariance matrices were heterogeneous, and thus the remaining analyses were based on the pooled data from Studies 1A and 1B to increase statistical power. The means and correlations for the pooled data are displayed in Table 1.

An assumption implicit in most current conceptualizations of working memory is that spans for storage-only memory tasks should be greater than those for storage-plus-processing memory tasks. That is, if there are some costs of simultaneous processing in storage-plus-processing memory tasks, then estimates of the capacity of memory involving only storage should be larger than estimates of the capacity of memory involving simultaneous storage and processing. The data in Table 1 reveal that this pattern was obtained with both the verbal tasks—VM versus VMP, $t(78) = 9.93$, $p < .05$—and the spatial tasks—SM versus SMP, $t(78) = 5.99$, $p < .05$.

A second prediction investigated in this study was that stronger relations between performance measures would be evident when the tasks placed greater demands on central processing. Two analyses were conducted to examine this prediction. The first analysis revealed that the correlation between the measures of verbal and spatial storage-only memory was not significantly different from 0 (i.e., r[VM − SM] = .10), whereas the correlation between the verbal and spatial storage-plus-processing memory measures was significantly greater than 0 (i.e., r[VMP − SMP] = .40, $p < .05$). Furthermore, the difference between the two correlations was also significant ($Z_2^* = 2.22$, $p < .05$; see Steiger, 1980, for the Z_2^* test of dependent correlations). The second analysis revealed that the correlation between the storage-plus-processing measures was still significant after using multiple regression procedures to partial the storage component out of each measure (i.e., $r[\mathrm{VMP}_{.vm}, \mathrm{SMP}_{.sm}] = .23$, $p < .05$).

Both of these analyses are therefore consistent with the predictions that greater processing requirements increase the demands on a central processor. The first analysis can be interpreted as comparing the relations between the verbal–symbolic and visual–spatial storage components with and without central processing involvement. The second analysis can be interpreted as determining the relation between the variances in the storage-plus-processing tasks when the variance attributable to the presumably passive storage components has been removed. Of particular importance from both analyses was the discovery that the correlation between the memory measures was significantly greater when the processing demands were increased—a result expected from the view that a common central processor is involved in both verbal–symbolic and visual–spatial working memory.

Study 2

Evidence from Study 1 supported the notion that the requirement of simultaneous processing increases the involvement of a central executive component in tasks of working memory. Studies 2 and 3 were therefore conducted to investigate the role of the central processor in age differences in working memory. The basic task used in these studies was the computation-span task (VMP) described in Study 1. This computation-span task has been found to be age sensitive in several previous studies (Salthouse, 1988; Salthouse & Mitchell, 1989; Salthouse & Prill, 1987). For example, in a recent study, Salthouse et al. (1989) found that among 120 adult men ranging from 20 to 79 years of age, computation span had a correlation of −.46 with chronological age. If less efficient use of the central processor in older adults is the cause of the age differences on the computation-span task, then older adults' performance on the VMP task should be relatively worse than on the VM task, because the latter task probably imposes fewer demands on the central processor. In other words, it was predicted that if less efficient processing is the cause of the age differences on working-memory tasks (as proposed by Craik & Rabinowitz, 1984; Gick, Craik, & Morris, 1988; Morris, Gick, & Craik, 1988; Stine & Wingfield, 1987), then there will be an Age × Task interaction, with larger age differences on the VMP task than on the VM task.

Method

Participants

The participants in Study 2 were the 38 young adults from Study 1B (21 men and 17 women) and 17 older community-dwelling adults (10 men and 7 women), ranging from 61 to 72 years of age (mean age of older participants = 66.47, *SD* = 4.00). The young adults reported an average of 13.9 years of education (*SD* = 1.48) and an average health rating of 1.6 (*SD* = 0.65) on a scale of 1 (*excellent*) to 5 (*poor*). The older adults reported an average of 14.9 years of education (*SD* = 1.20) and an average health rating of 1.8 (*SD* = 0.83) on the 5-point scale.

Procedure

Each participant performed all the tasks in one 90-min session. The sequence of tasks, outlined in the description of the first session of Study 1B, was VM, VMP, VMP, and VM.

Results and Discussion

Mean spans for young and older adults in the two tasks are presented in Figure 2. Means (with standard deviations in parentheses) for the tasks were as follows: VM = 6.99 (0.75) and VMP = 5.30 (1.36) for the young adults, and VM = 5.76 (1.07) and VMP = 4.18 (1.30) for the older adults. An analysis of variance (ANOVA) indicated that there was a main effect for both age, $F(1, 53) = 20.43$, $MS_e = 1.69$, $p < .05$, and task, $F(1, 53) = 85.75$, $MS_e = 0.84$, $p < .05$, but the Age × Task interaction was not significant, $F(1, 53) = 0.01$, $MS_e = 0.84$, $p > .05$.

Another way of examining the possibility that the age differences might vary across the two tasks is to express each older adult's performance in terms of standard deviation units of young adults' performance for that task. This comparison, which reflects age differences in population-referenced rather than absolute units, also failed to reveal a larger age difference on the VMP task than on the VM task (i.e., mean zVMP = −0.82, and mean zVM = −1.63).

Finally, an additional means of determining whether there was a greater age difference on the task involving more processing is to express each participant's performance in terms of the ratio of his or her performance on VMP to that individual's performance on VM. An analysis of these ratios would indicate whether the decline in performance on the task involving more processing (relative to the performance on the task involving minimal processing) is proportionately similar for both older and younger adults. This analysis also failed to reveal a significant age difference, $t(53) = 0.58$, $p > .05$. All of the analyses of

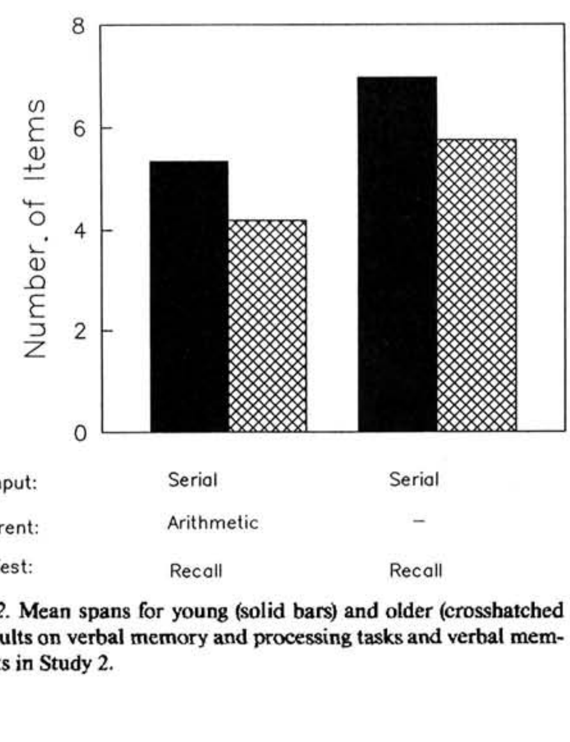

Figure 2. Mean spans for young (solid bars) and older (crosshatched bars) adults on verbal memory and processing tasks and verbal memory tasks in Study 2.

Study 2 are therefore inconsistent with the prediction that greater reliance on the central processor in the VMP task would result in larger age differences than in the VM task.

Study 3

The results from Study 2 indicate that the age differences in memory span seem to be independent of the amount of concurrent processing required in the task. However, Light and Anderson (1985) suggested that even simple recall of digits in the order in which they were presented involves a certain amount of simultaneous storage and manipulation. Therefore, even the no-arithmetic version of the computation-span task (VM) may have required appreciable concurrent processing because the participant had to remember early items during the presentation of later ones and to remember later items during the recall of early ones.

Study 3 was designed to extend Study 2 by examining performance in five tasks that were assumed to correspond to a rough continuum of the amount of required processing. The first span task (consisting of serial input, concurrent arithmetic processing, and a recall test) was the VMP task described in Study 1. In the remaining tasks, no arithmetic operations were required, and the stimuli consisted solely of the to-be-remembered numbers.

In the second task, the to-be-remembered numbers were presented serially, and the test was recall, as in the VM task from the previous studies. In the third task, the numbers were presented simultaneously, but memory was still assessed via recall. The numbers in the fourth task were presented serially, but in this condition, memory was assessed in a recognition (same vs. different) format. In the final task, the numbers were presented simultaneously, and the memory test was recognition.

Although conceptualizing the tasks as falling along a single continuum of processing demands is somewhat arbitrary, we assumed that serial presentation required more processing than simultaneous presentation because participants had to remember early items during the presentation of later ones. In addition, we assumed that recall testing should require more processing than recognition testing because the participants had to remember later items during the recall of early ones.

Method

Participants

The participants in Study 3 were 41 young adults (14 men and 27 women) ranging from 18 to 26 years of age (M = 19.48, SD = 1.60) and 40 older adults (10 men and 30 women) ranging from 55 to 83 years of age (M = 68.62, SD = 6.15). None had participated in Study 1 or 2. The young adults reported an average of 13.6 years of education (SD = 1.36) and an average health rating of 1.5 (SD = 0.75) on the 5-point scale. The older adults reported an average of 14.8 years of education (SD = 2.28) and an average health rating of 1.6 (SD = 0.90).

Procedure

Participants performed all the tasks in one 90-min session. The tasks were performed once in the order described earlier and were then performed again in the reverse order to allow for assessment of the reliability of the measures. Trials in the first task were presented on a computer screen at a rate of 3 s per problem. All other tasks with serial input were presented at a rate of 0.75 s per digit. The tasks with simultaneous input were presented at a rate of 0.5 s per digit plus a constant of 1 s to allow the participant to adjust to the stimuli. Recall and recognition memory tests were self-paced. In the recall tests, participants typed the numbers in the order in which they had been presented, and in the recognition tests, participants compared a series of numbers and decided whether they were the same or different. Different stimuli in the recognition tests were distinguished from the presented items by a single, randomly positioned digit.

The procedure for assessing spans in Study 3 was similar to the double-random-staircase procedure used in Studies 1 and 2 for the recall tasks but was modified slightly to accommodate the recognition measures. Specifically, in the assessment of spans in the recognition tasks, the number of digits presented on a trial did not increase until 3 of 4 trials were correct with a given number of digits. However, two independent sequences were still used, and the span was still computed as the average of the estimates from the two sequences.

Results and Discussion

Spans for each of the tasks are presented in Figure 3. Means (with standard deviations in parentheses) across the tasks listed in the figure were as follows: 4.61 (1.46), 5.91 (1.07), 7.18 (1.09), 10.43 (1.39), and 12.09 (1.84) for the young and 2.58 (1.37), 4.19 (1.27), 5.09 (1.60), 8.81 (1.38), and 9.56 (1.42) for the older adults. The age differences seemed to remain approximately constant across all of the tasks. This impression is supported by an ANOVA, because the main effects of age, $F(1, 79) = 79.91$, $MS_e = 5.04$, and task, $F(4, 79) = 300.91$, $MS_e = 1.21$, were significant ($ps < .05$), but their interaction was not, $F(4, 79) = 2.17$, $MS_e = 1.21$, $p > .05$.

As in Study 2, the data were also analyzed after first converting the values for each older adult in terms of standard scores relative to the distribution of young adults in each task. Expressed in this way, the means across the tasks listed from left to right in Figure 3 were −1.39, −1.61, −1.92, −1.16, and −1.38, respectively. Note that the greatest age difference was on the task involving only a moderate amount of processing and that the task involving the most processing had an intermediate age difference.

In addition, to make a more direct comparison between the tasks in this study and those in Study 2, each participant's performance was expressed in terms of the ratio of his or her performance on the first task (VMP) to that individual's performance on the second task (VM). Again, scores represented in this way indicated whether older adults' performance on the VMP task was significantly worse than younger adults' performance on the VMP task relative to their performance on the VM task. Unlike Study 2, this analysis revealed a significant age difference, $t(79) = -2.02$, $p < .05$. A possible explanation for the significant difference in this study and absence of significant difference in Study 2 is that there was a greater age range in this study than in Study 2. That is, in Study 2 the ages of the older participants ranged from 61 to 72 years. However, in Study 3, the ages of the older participants ranged from 55 to 83 years.

Because of this apparent discrepancy, the correlation between age and the ratio of VMP to VM was calculated for Studies 2 and 3. In Study 2, the correlation was not significantly different from 0 ($r = -.09$), whereas, in Study 3, the correlation

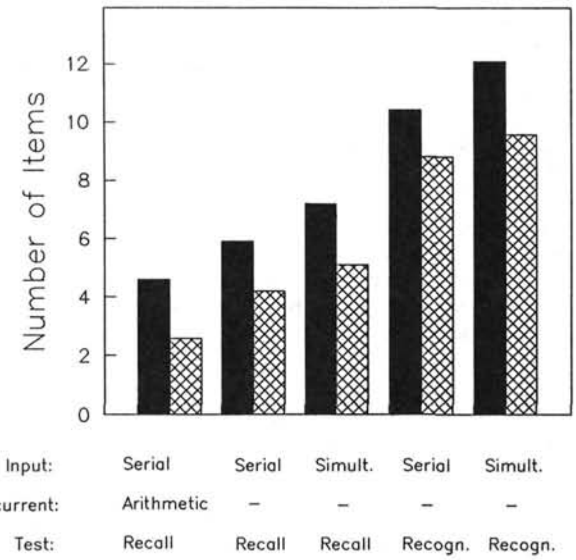

Figure 3. Mean spans for young (solid bars) and older (crosshatched bars) adults on tasks in Study 3.

between age and the ratio score was significantly different from 0 ($r = -.27$, $p = .01$). However, a comparison of the ratios in the two studies in the form of an Age × Experiment ANOVA did not reveal a significant interaction ($p > .05$), thus providing no basis for claiming that the results from the two studies are different from one another.

The results of this study confirm and extend those from Study 2. That is, in Study 2, similar age differences were found on tasks that involve presumably modest to substantial processing requirements. In Study 3, both of the tasks from Study 2, as well as new tasks hypothesized to involve considerably less processing, also revealed relatively constant age differences.

As noted earlier, the ordering of the tasks on the hypothesized continuum of processing demands was somewhat arbitrary, and we do not assume that the continuum necessarily reflects different amounts of exactly the same type of processing. Nevertheless, memory performance varied in the expected direction across the tasks, and yet the magnitude of the age differences remained roughly equivalent.

General Discussion

The goals of the studies in this article were to investigate (a) the plausibility of the idea that increasing the requirements of simultaneous processing places greater demands on a common central processor and (b) the effects of varying the amount of simultaneous processing on the magnitude of age differences in measures of working-memory performance.

Results from the first study indicated that when processing requirements were increased, measures of storage capacity were lower, but the relationship between them was higher. These findings are consistent with the assumption that there is greater involvement of a common or central processing component when both storage and processing are required, compared with when only storage is required. Therefore, contrasting performance in tasks with different processing requirements is a reasonable means of determining the role of a central processor in age differences in working memory. The second and third studies were based on the reasoning that if there is a decrease with age in the efficiency of central processing, then greater performance impairments might be expected for older adults than for younger adults as the processing demands are increased. The results of the studies presented here did not, however, support these predictions.

The current findings are somewhat surprising because they are inconsistent with suggestions of several researchers (e.g., Baddeley, 1986; Craik & Rabinowitz, 1984; Gick et al., 1988; Morris et al., 1988; Stine & Wingfield, 1987) that it is the requirements of central processing that are responsible for most of the age differences in working memory. In an attempt to resolve the apparent discrepancy between the present results and those of previous studies, we conducted a search to find published studies in which young (mean age less than 30) and older (mean age over 60) adults were administered both a simple and a complex version of a memory-span task. The results of this search are summarized in Table 2.

Two comparisons of data from Table 2 are particularly relevant to the question of whether age differences increase with greater processing requirements. The first is a contrast of the ratio of young to old performance in the simple tasks and the ratio of young to old performance in the complex tasks. Although many of the studies listed did not report a significant difference between these two measures, when viewed as a group the latter values were significantly larger than the former, $t(19) = -3.75$, $p < .001$. Comparison of the entries in the last two columns and can be interpreted to reflect the storage costs of simultaneous processing because lower numbers indicate greater discrepancies between complex and simple spans and therefore greater requirements of concurrent processing. Once again, the contrasts reveal greater processing costs for older adults than for young adults, $t(19) = 4.66$, $p < .000$, when the studies are combined in a meta-analysis. This approach ignores the variation in sample sizes and does not take differences in variability into account. However, because some studies did not report variability, this approach to determining the overall effect seems reasonable (and conservative).

This small-scale meta-analysis provides a broader perspective within which the results of the current studies can be interpreted. Although the statistical analyses in Studies 2 and 3 did not reveal significant interactions of age and task, the pattern of results appears generally consistent with those of other studies in revealing slightly greater age differences in versions of the span task requiring more concurrent processing. However, the results summarized in Table 2 clearly indicate that age differences are frequently found in the simple versions of span tasks presumed to have minimal processing requirements. In fact, the average age difference in the forward digit-span task (i.e., 8% advantage for young adults) is more than half that in the backward digit-span task (i.e., 14% advantage for young adults). Therefore, age-related differences in both the storage and the processing components seem to contribute to age-related differences in working memory.

Table 2
Mean Spans for Simple and Complex Tasks for Young (Y) and Older (O) Adults

	Simple			Complex			C/S	
Task/study	Y	O	Y/O	Y	O	Y/O	Y	O
Forward/backward digit span								
Botwinick & Storandt, 1974	7.76	7.45	1.04	7.38	6.45	1.14	.951	.866
Bromley (1958)	6.8	6.6	1.03	5.4	4.9	1.10	.794	.742
Burke & Yee (1984)	7.6	6.8	1.12	6.3	5.6	1.13	.829	.824
Cerella et al. (1986)	6.58	6.53	1.01	5.42	4.69	1.16	.824	.718
Chiarello et al. (1985)	7.4	7.1	1.04	5.4	5.1	1.06	.730	.718
Chiarello & Hoyer (1988)	7.1	6.5	1.09	5.6	5.1	1.10	.789	.785
Clark & Knowles (1973)	6.72	6.75	0.99	4.61	4.43	1.04	.686	.656
Dobbs & Rule (1989)	7.06	6.6	1.06	5.57	5.02	1.11	.793	.761
Ferris et al. (1980)	7.3	7.2	1.01	5.7	5.5	1.04	.781	.764
Gilbert (1941)	6.87	6.06	1.13	5.53	4.36	1.27	.805	.719
Hooper et al. (1984)	7.04	6.58	1.07	5.46	5.00	1.09	.776	.760
Light & Anderson (1985)	7.42	6.89	1.08	6.09	5.67	1.07	.821	.823
Mueller et al. (1979)	7.5	6.8	1.10	6.5	5.0	1.30	.867	.735
Schneider et al. (1975)	6.93	5.87	1.18	5.53	4.46	1.24	.798	.760
Average	7.15	6.70	1.07	5.75	5.09	1.13	.803	.759
Word span/reading-listening span								
Light & Anderson (1985)	5.22	4.73	1.10	3.44	3.02	1.14	.659	.638
Wingfield et al. (1988)	6.02	5.15	1.17	4.00	2.43	1.65	.664	.472
Gick et al. (1988)	4.29	3.90	1.10	2.83	2.08	1.36	.660	.533
Digit span/computation span								
Study 2	6.99	5.76	1.21	5.30	4.18	1.27	.758	.726
Study 3	5.91	4.19	1.41	4.61	2.58	1.79	.780	.616

Note. Y/O = ratio of young to older performance; C/S = ratio of complex to simple spans.

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