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Within-Context Assessment of Age Differences in Working Memory

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Five experiments were conducted to investigate the mechanisms by which age-related reductions in working memory capacity might mediate age-related declines in cognitive functioning. A prototypical cognitive task, cube comparison, was implemented on a computer to allow measures of the availability of different types of information while subjects were attempting to solve the task. Young and old adults were equivalent in a measure postulated to reflect the temporary preservation of untransformed stimulus information. However, older adults, relative to young adults, exhibited greater reductions in accuracy as the processing requirements increased, and they made significantly more redundant or repetitive requests for information. These results are consistent with the view that increased age may be associated with a decreased ability to transform or abstract information while also preserving the products of earlier processing.

A CURRENTLY popular hypothesis to account for age-related differences in cognitive performance attributes many of those differences to variations in the effectiveness of working memory. The idea that limitations in the simultaneous processing and storing of information might be responsible for declines in cognitive functioning associated with increased age was first discussed by Welford (1958), and it is still considered one of the most viable hypotheses for explaining cognitive aging phenomena (see Salthouse, 1990, for a review of relevant research).

Most of the research relevant to the working-memory hypothesis of age differences in cognitive performance has been correlational in nature. That is, researchers have collected measures of working memory functioning and measures of performance on various cognitive tasks, and then have examined either the correlations between these measures, or the correlations between age and cognitive performance after partialling the measure of working memory. Results from such analyses have been mixed. Some studies have reported moderate correlations between measures of working memory and measures of cognitive performance, and substantial attenuation of the age differences in cognition after partialling out the variance associated with the working memory measure (e.g., Salthouse, Mitchell, Skovronek, & Babcock, 1989), but others have not (e.g., Light & Anderson, 1985).

A disadvantage of the correlational approach is that, even when it is successful in indicating that significant relations do exist between measures of working memory and measures of cognitive performance, it is not necessarily very informative about the mechanisms responsible for that relation. The research described in this report was an attempt to investigate more precisely how age-related limitations in working memory might lead to age-related impairments in cognitive functioning. Our fundamental hypothesis was that increased age is associated with poorer performance on many cognitive tasks because of a decreased ability to preserve relevant information while engaged in the processing required for the task. We therefore designed tasks that allowed us to assess the availability of various types of information while subjects were attempting to perform moderately complex cognitive activities.

Four separate measures, each based on different procedures and sets of assumptions, were hypothesized to reflect somewhat different aspects or manifestations of working memory. One measure, which can be termed an out-of-context assessment (cf. Salthouse, 1990) because it was not obtained during an on-going cognitive task (but instead from a task deliberately designed to assess properties of working memory) was the spatial line span. This measure represented the maximum number of line segments the individual could remember while also carrying out specified processing (creating new lines between designated points), and was intended to provide an estimate of the subject's general capacity for the simultaneous processing and storage of spatial information.

Within-context measures will necessarily vary as a function of the context, or particular cognitive activity being performed. The primary task in the experiments in the current project was a computer-administered version of the cube comparison test. This test consists of the display of two isometric drawings of cubes with letters in varying orientations on each face. Subjects are required to determine whether the drawings could represent the same cube, given the restriction that each face on a given cube contains a different letter. The task is relatively complex and can involve considerable mental processing, as revealed in the following task analysis.

Consider the pairs of cubes in Figure 1. One strategy for deciding whether the pairs of drawings could represent the same cube is to first determine whether or not corresponding faces have identical letters and orientations. If they do, as is the case with the pair of cubes illustrated in panel A, then the processing requirements are minimal and a SAME decision can be made after matches are verified on each pair of corresponding faces. However, when corresponding cube faces do not have identical letters, as in panels B and C, the amount of mental processing increases substantially. For example, in solving the problem displayed in panel B, a subject might engage in the following steps. First, on discovering that the front faces of the left and right cubes did not match, a search might be initiated among the remaining faces on the right cube to find a face with the same letter as that on the front face of the left cube (i.e., an A). In this problem, a match is found on the top face of the right cube, which might lead to the hypothesis that the left cube had been rotated up to produce the configuration illustrated in the right cube. This possibility can be checked by examining the right face of the right cube, because if the cube had been rotated up, then the letter on that face should match the letter on the right face of the left cube with a 90° clockwise rotation. Finally, in order to confirm the suspected upward rotation, the letter on the front face of the right cube should be reexamined to ensure that it does not match the letter on the top face of the left cube, because that letter (F) should now be hidden.

The sequence of steps just outlined is only one of several possible strategies for performing the cube comparison task, but it should be obvious that the task requires considerable mental computation and updating of memory. Indeed, the preceding discussion suggests that at least three distinct types of information may have to be maintained and coordinated in order to perform the task successfully: information about the identity and orientation of letters within specific cube faces (e.g., the front face on the left cube contains an upright A); information about the relations among face contents (e.g., the top face on the right cube matches the front face on the left cube); and information about the consequences of possible transformations (e.g., an upward rotation of the cube will move the contents of the front face to the top face and will lead to a 90° clockwise shift in the orientation of the letter on the right face). Because requirements of simultaneous processing and storage are usually considered defining characteristics of working memory, successful performance on the cube comparison test clearly seems to involve working memory. Several measures in the present experiments were therefore intended to assess various properties of working memory as it is used during the performance of computer-administered versions of the cube comparison test.

One measure was based on the assumption that different types of trials vary in the demands they make on working memory. That is, in some trials, such as that illustrated in panel A of Figure 1, the demands on working memory seem minimal, whereas in other trials, such as those illustrated in panels B and C of Figure 1, the demands appear much more substantial. An indirect measure of working memory functioning might therefore be derived by computing the difference between decision accuracy in trials with minimal memory demands and decision accuracy in trials with large memory demands. The rationale is that subjects with larger or more effective working memories should, other things being equal, exhibit smaller reductions in decision accuracy with an increase in processing (and working memory) requirements than subjects with smaller or less effective memories. Larger amounts of computation and mental bookkeeping may lead to increases in errors because of overloading of the capacities of subjects with small or ineffective working memories, but the consequences of greater demands on storage and processing should be less severe in subjects with larger or more effective working memories.

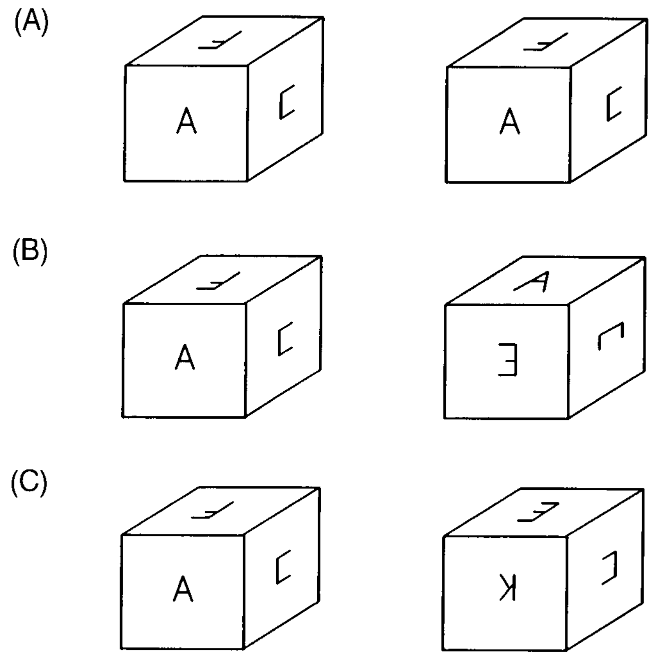

Figure 1. Illustration of matching cube stimuli with orientation discrepancies of (A) 0°, (B) 90°, and (C) 180°.

The remaining measures of working memory were derived from a modified version of the cube comparison task in which the contents of only one cube face could be viewed at any given time. Requiring subjects to make explicit requests (via computer commands) to view the contents of specific cube faces allowed two assessments of working memory functioning. One was indirect and based on the number of times the same cube face was reexamined in a single trial. The assumption is that these repetitions occur because the subject is unable to maintain relevant information while it is being processed, and hence a larger number of repeated information requests may be symptomatic of a smaller or less effective working memory.

The final measure of working memory was based on the accuracy of recognition judgments about previously viewed information. That is, on some of the trials in the successive viewing condition, subjects were tested with probes of the contents of cube faces examined earlier in that trial. For example, if on a given trial the subject viewed the cube faces in the sequence, front face on the left cube, top face on the left cube, and front face on the right cube, the trial might be interrupted by the presentation of a probe displaying a letter in the front face of the left cube. The task for the subject in these special probe trials was to decide whether the probe stimulus matched, in both identity and orientation, the letter visible in that face a few moments earlier on that same trial. The rationale is that subjects with larger or more effective working memories should be better able to maintain accurate information about the contents of previously viewed cube faces, and should therefore make fewer errors in these recognition decisions than subjects with poorer working memories. These probe measures also provide a means of monitoring whether the information was encoded when initially viewed because decisions to the probes can only be accurate if the information was successfully encoded.

It is important to emphasize that the four measures just described were not necessarily assumed to reflect the same aspects of working memory. Instead, they are postulated to reflect different manifestations of working memory as it is used in the processing involved in a specific cognitive task. Although it might be interesting to examine correlations among the measures to investigate their degree of independence, small sample sizes and low reliabilities of the measures made analyses of this type of limited value in the present project.

Five experiments are reported, all involving independent samples of young and old adults, but varying somewhat in procedures and specific measures. Experiments 1–3 involved the computer cubes task described above and also included the line span measure of spatial working memory. Subjects in Experiment 4 performed both the computer cubes task and a computer matrix task patterned after the Raven's Progressive Matrices Test to investigate the generality of certain findings. The matrix task was selected for this purpose because it is similar to the cube comparison task, in that successful performance appears to require the abstraction of information about the relations among discrete pieces of information. Experiment 5 differed from the earlier experiments by including the probe recognition accuracy measure. Because significant age differences were expected in the measures of time and accuracy of cube comparison performance, the question of primary interest in each experiment was the presence or absence of age differences in the available measures of working memory.

Experiments 1–3

The first three experiments were very similar and differed only with respect to the type of stimulus displays on the cubes (Experiments 1 vs 2 and 3), or whether the subjects performed additional tasks in other sessions in the project (Experiments 1 and 2 vs 3). Measures obtained in these experiments were the line span measure of out-of-context working memory, and the accuracy difference and the number of repeated information requests measures of working memory obtained during the performance of the cube comparison task.

Method

Subjects

Descriptive characteristics of the young and older adults who participated in Experiments 1–3 are summarized in Table 1. The older participants in Experiments 1 and 3 were recruited primarily from alumni of the Georgia Institute of Technology, whereas those in the other studies were recruited from the general community. All young adults were students enrolled in undergraduate psychology courses at the Georgia Institute of Technology. Entries in the Education row refer to the self-reported years of formal education, and those in the Health row correspond to a self-rating of health on a scale ranging from 1 = Excellent to 5 = Poor.

Table 1. Means (and Standard Deviations) of Sample Characteristics in the Five Experiments

	Experiment 1	Experiment 2	Experiment 3	Experiment 4	Experiment 5
Sample size					
Young	24	26	50	50	50
Old	24	25	20	46	30
Gender (% female)					
Young	0	62	0	64	54
Old	0	56	0	65	57
Age					
Young	19.6 (1.2)	20.2 (2.5)	19.9 (2.7)	20.2 (2.5)	20.1 (2.2)
Old	60.7 (4.3)	68.2 (5.4)	68.0 (6.2)	68.5 (4.7)	67.4 (6.1)
Education					
Young	13.7 (1.3)	14.3 (2.1)	13.7 (2.1)	13.9 (1.2)	14.0 (1.5)
Old	17.6 (3.5)	15.2 (1.9)	16.8 (2.0)	14.7 (2.1)	15.1 (2.2)
Health (1 = excellent, 5 = poor)					
Young	1.63 (0.9)	1.46 (0.6)	1.60 (0.6)	1.44 (0.6)	1.34 (0.5)
Old	1.46 (0.8)	1.64 (0.8)	1.60 (0.7)	2.02 (0.8)	1.73 (0.8)
ETS cube comparisons (no. correct)					
Young	14.0 (4.2)	12.0 (4.5)	12.7 (4.1)	NA	NA
Old	10.4 (3.9)	8.6 (3.0)	8.1 (3.1)	NA	NA
	$t(46) = 3.10$*	$t(49) = 3.22$*	$t(68) = 4.58$*		
Life span					
Young	3.25 (0.98)	3.48 (0.93)	3.56 (1.13)	NA	NA
Old	2.00 (0.61)	1.90 (0.59)	2.47 (1.06)	NA	NA
	$t(44) = 5.19$*	$t(49) = 7.21$*	$t(61) = 3.33$*		

Note. Degrees of freedom vary within experiments because data are missing for some participants with some measures. NA indicates that test was not administered.

*$p < .01$.

Experimental Tasks

ETS cube comparisons. — The first half of the ETS Cube Comparisons Test (Ekstrom, French, Harman, & Dermen, 1976) was administered according to the published instructions. Performance was summarized in terms of the number of items answered correctly in the allotted time (3 minutes).

Line span. — This task required the subject to remember the location of lines (connecting invisible points in a 4×4 matrix) on a computer display, while simultaneously using a hand-held mouse to create lines between X's also present in the display. (See Babcock and Salthouse, 1990, for further details and an illustration of a typical trial in this task.) The number of successive line displays presented prior to a recall instruction varied according to a double random staircase psychophysical procedure to determine the maximum number that could be accurately reproduced, while also correctly performing the line creation task. Subjects reproduced lines in the recall phase by using the mouse to connect points within a 4×4 matrix. An estimate of the individual's spatial working memory span was obtained by averaging the values from the two independent sequences after they had converged to within two items for four consecutive trials.

Computer cubes. — Two different formats were used with the computer-controlled cube comparison task: simultaneous presentation of all cube faces and successive presentation of one face at a time. The latter condition consisted of displays of the cube outlines without letters in the faces. In Experiment 1, the faces on the left cube were always visible in the successive condition, and only those on the right cube were to be examined successively by the subject. In Experiments 2 and 3, however, the contents of the cube faces were not visible in the successive condition unless specifically requested, and only one face on either cube could be viewed at any given time. The particular cube face to be examined was indicated by using a hand-held mouse to move a cursor within the boundaries of the relevant face. Instructions in the successive conditions emphasized that subjects should try to achieve the highest possible accuracy in their decisions, but that the number of cube faces viewed prior to making a decision should be kept to a minimum.

In both the simultaneous and successive conditions, the decision requirements were identical to those in the ETS Cube Comparisons Test (i.e., the task was to decide whether the two displayed configurations could be representations of the same cube). Subjects were informed that the two configurations could portray the same cube even if the contents of the faces were not in one-to-one correspondence. Several examples with differing orientations between the two cubes were carefully described to ensure that all subjects understood the task.

Upon reaching a decision, the subject used the mouse to move the cursor to a query box located slightly above and between the cubes. The subject then pressed the right mouse button if he/she thought the cubes were the SAME, or the left mouse button if the configurations were thought to represent DIFFERENT cubes.

As illustrated in Figure 1, the stimuli consisted of isometric representations of two cubes, with a unique capital letter on each face (top, front, right) of a given cube. Letters could be in any of four 90° increments of rotation (upright, 90° to the left or right, or inverted 180°). Letters with both horizontal and vertical symmetry, or which when rotated resembled another letter (e.g., H, I, M, N, O, S, W, X and Z), were not used in order to avoid ambiguity with respect to orientation or identity.

Procedure

Subjects in Experiment 1 performed the ETS Cube Comparisons Test, the line span task, and the simultaneous and successive versions of the computer cubes task. There were 2 blocks of trials in the simultaneous condition, a practice block of 4 trials and an experimental block of 24 trials, and 3 trial blocks in the successive condition, a practice block of 4 trials and 2 experimental blocks of 60 trials each. More trials were presented in the successive condition than in the simultaneous condition in an attempt to obtain stable estimates of the number of information (i.e., cube face) requests.

Experiments 2 and 3 involved identical procedures, but Experiment 3 was conducted as part of a larger project in which subjects performed a number of spatial visualization tasks in four additional sessions (Salthouse, Babcock, Mitchell, Palmer, & Skovronek, 1990; Salthouse, Babcock, Skovronek, Mitchell, & Palmon, 1990). The computer cubes task was presented for a 4-trial practice block and a 36-trial experimental block in the simultaneous condition, and for a 4-trial practice block and three 36-trial experimental blocks in the successive condition.

RESULTS AND DISCUSSION

Before describing the results of the experimental tasks, it is important to note that, in line with the findings of earlier related research (see Salthouse, 1982, for a review), the young adults scored significantly higher than the older adults on the standard paper-and-pencil version of the Cube Comparisons Test (Table 1). These results suggest that the present samples are generally similar to those of earlier studies, although the older adults are highly educated relative to the general population. A second noteworthy finding evident in Table 1 is that the young and old adults differed significantly in the line span measure of spatial working memory. This result is also consistent with the findings of other studies in which young adults have been found to perform better than older adults in out-of-context assessments of working memory (see Salthouse, 1990, for a review).

Means for the measures of percentage-correct decisions and median seconds per item in the simultaneous and successive versions of the computer cubes tasks are presented in Table 2. It can be seen that, with the exception of the accuracy measures in Experiment 1, the older adults were significantly less accurate and slower in their decisions than the young adults. One possible reason for the smaller age differences in Experiment 1 relative to Experiments 2 and 3 is that the sample of older adults in that study was both younger and had more years of education than the samples of older adults in the other experiments.

Table 2 also contains the correlations between the time and accuracy measures from the simultaneous and succes-

Table 2. Means (and Standard Deviations) of Performance Measures from the Computer Cubes Tasks in Experiments 1–5.

	Experiment				
	1	2	3	4	5
Computer cubes (simultaneous) accuracy (percentage correct)					
Young	92.0 (8.4)	90.1 (6.4)	89.0 (8.3)	92.2 (12.0)	95.2 (6.6)
Old	90.1 (8.7)	69.7 (14.2)	80.4 (13.6)	79.6 (15.1)	79.3 (15.8)
	$t(46) = .77$	$t(49) = 6.67$*	$t(68) = 3.21$*	$t(94) = 4.56$*	$t(78) = 6.28$*
Computer cubes (simultaneous) time (seconds per problem)					
Young	7.22 (2.44)	10.61 (4.23)	8.10 (2.22)	6.44 (2.15)	8.52 (2.52)
Old	12.04 (4.81)	15.86 (4.69)	16.45 (7.36)	16.09 (6.36)	15.68 (4.76)
	$t(46) = -4.37$*	$t(49) = -4.21$*	$t(68) = -7.31$*	$t(88) = -9.96$*	$t(74) = -7.52$*
Computer cubes (successive) accuracy (percentage correct)					
Young	94.6 (5.4)	87.5 (7.8)	82.9 (10.0)	83.2 (13.7)	83.7 (14.1)
Old	90.5 (8.0)	67.9 (14.4)	72.1 (17.8)	65.2 (12.9)	64.4 (14.7)
	$t(46) = 2.09$	$t(49) = 6.08$*	$t(68) = 3.22$*	$t(93) = 6.60$*	$t(78) = 5.83$*
Computer cubes (successive) time (seconds per problem)					
Young	9.21 (1.60)	16.22 (5.15)	14.85 (4.72)	15.38 (4.55)	17.10 (7.06)
Old	16.36 (8.31)	29.52 (11.67)	28.60 (10.86)	29.60 (11.12)	32.64 (16.41)
	$t(46) = -4.14$*	$t(49) = -5.30$*	$t(68) = -7.42$*	$t(89) = -8.21$*	$t(74) = -5.77$*
Correlation: simultaneous accuracy with successive accuracy					
Young	.56*	.59*	.62*	.64*	.33
Old	.82*	.74*	.77*	.58*	.46
Correlation: simultaneous time with successive time					
Young	.55*	.56*	.46*	.47*	.24
Old	.60*	.46	.46	.41	.14
Computer cubes (simultaneous) accuracy difference (0°–180° trials)					
Young	−1.0 (18.8)	10.9 (20.5)	8.3 (17.3)	6.0 (15.0)	3.7 (13.2)
Old	16.7 (15.9)	38.7 (26.2)	21.7 (25.4)	27.2 (23.9)	20.0 (23.7)
	$t(46) = -3.52$*	$t(49) = -4.22$*	$t(68) = -2.53$*	$t(94) = 5.24$*	$t(78) = -3.96$*

Note. Degrees of freedom vary within experiments because data are missing for some participants with some measures.
*$p < .01$.

sive versions of the computer cubes task. Notice that most of the correlations are in the moderate range, suggesting that similar processes appear to be involved in the two task versions despite different methods of presentation. This is an important finding in the present context, because it provides some assurance that changing from a simultaneous to a successive format did not substantially alter the basic nature of the task.

Although not presented in Table 2, multiple correlations were also computed between the time and accuracy measures in the simultaneous computer cubes task and the score on the paper-and-pencil Cube Comparisons Test. The multiple Rs (all significant at $p < .01$) across Experiments 1–3 were .52, .78, and .40, respectively, for young adults, and .63, .60, and .53, respectively, for older adults. These moderate within-group relations suggest that there was also overlap in the processes used in the conventional paper-and-pencil version and in the experimental computer-administered versions of the Cube Comparisons Test.

Accuracy of trials in the simultaneous and successive versions of the computer cubes task was computed as a function of the orientation discrepancy between the cubes. The three discrepancies illustrated in Figure 1 (i.e., 0°, 90°, and 180° along a single axis) were common across all experiments, and thus the analyses focused on these three trial types.

Figure 2 (simultaneous condition) and Figure 3 (successive condition) illustrate the mean percentage correct values for young and old adults as a function of the angular deviation between the two cubes. It is clear in both figures

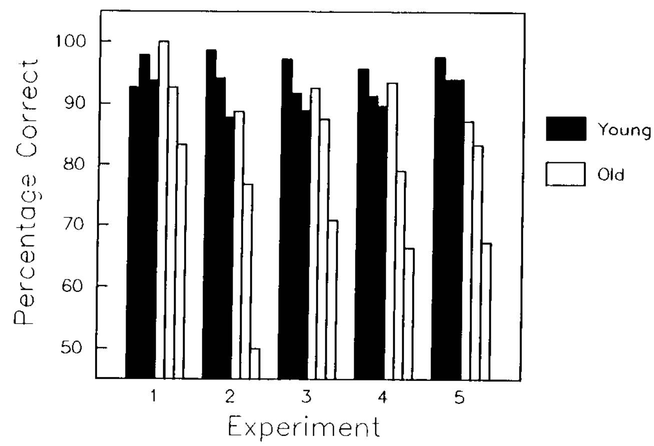

Figure 2. Decision accuracy for young and old adults in the simultaneous condition of the computer cubes task as a function of the orientation discrepancy between cubes. Successive bars from left to right in each cluster correspond to the means for trials with 0°, 90°, and 180° orientation discrepancies.

that the reduction in accuracy with greater orientation discrepancy between the cubes was larger for older adults than for young adults. This pattern is reflected in the interaction terms in age-by-orientation analyses of variance (ANOVA), which were significant ($p < .01$) in all experiments (including Experiments 4 and 5 to be reported later) for the simultaneous (all F's > 5.7) task, and in all but Experiment 1 for the successive tasks (Experiment 1, $F = 1.0$, all other F's > 6.4).

As proposed in the introduction, the demands on working memory are likely to be greater as the orientation discrepancy between the cubes increases, and therefore the results displayed in Figures 2 and 3 can be interpreted as evidence for the existence of age differences in one aspect of working memory. In order to derive a quantitative estimate of this property of working memory functioning, each individual's decision accuracy in the 180° simultaneous trials was subtracted from his or her decision accuracy in the 0° simultaneous trials. Means of these difference measures, and results of t-tests contrasting values of young and old adults, are displayed in Table 2. Notice that, in each experiment, young adults had significantly lower accuracy difference scores.

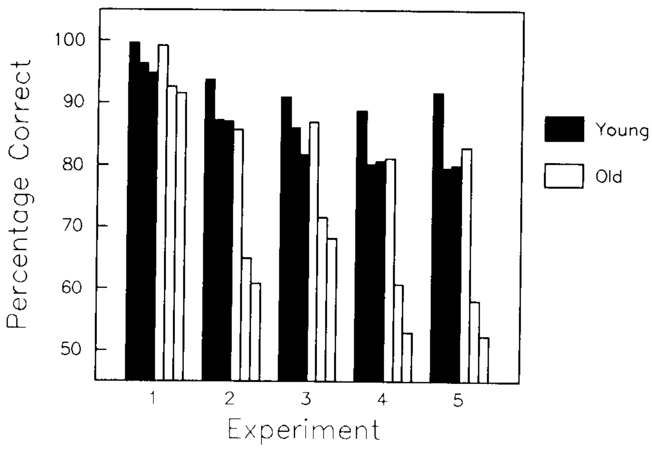

Figure 3. Decision accuracy for young and old adults in the successive condition of the computer cubes task as a function of the orientation discrepancy between cubes. Successive bars from left to right in each cluster correspond to the means for trials with 0°, 90°, and 180° orientation discrepancies.

Two measures of information seeking were extracted from analyses of performance in the successive task. One measure was the number of unique information requests about the contents of different cube faces. Because there were three blank faces in Experiment 1 and six blank faces in Experiments 2 and 3, the maximum number of unique information requests was three for Experiment 1 and six for Experiments 2 and 3. The second measure of information seeking was the number of repeated information requests in which previously viewed cube faces were reexamined.

Summary statistics for the mean numbers of unique and repeated information requests for young and old adults are displayed in Table 3. In addition to comparing the raw means of young and old adults, two further analyses were conducted to take accuracy differences into account. It is desirable to incorporate some type of adjustment for accuracy because comparisons of process measures (such as number and type of information requests) may not be very meaningful if the outcomes of those processes (in the form of decision accuracy) are not at least roughly equivalent. In other words, inclusion of subjects performing near a chance level of accuracy makes it difficult to detect individual differences in how the task is successfully performed. One attempt to adjust for accuracy was an analysis of covariance

Table 3. Means (and Standard Deviations) of the Number of Information Requests for Correct Trials and Recognition Accuracy in the Successive Computer Cubes Task, Experiments 1–5.

	Experiment				
	1	2	3	4	5
Average no. of unique information requests per trial					
Young	2.71 (.06)	5.75 (.37)	5.72 (.65)	5.43 (.74)	5.38 (.77)
Old	2.73 (.08)	5.73 (.68)	5.38 (.97)	5.87 (.25)	5.49 (.55)
F	.46	.01	2.75	14.61*	.39
F after accuracy adjustment	.01	.01	.50	23.75*	9.32*
Young > = 75%	2.71 (.06)	5.83 (.17)	5.83 (.53)	5.62 (.28)	5.65 (.22)
Old > = 75%	2.72 (.07)	5.41 (1.16)	5.47 (.64)	5.70 (.35)	5.39 (.69)
F	.24	3.03	3.31	.57	2.68
Average no. of repeated information requests per trial					
Young	.19 (.18)	5.05 (2.22)	4.52 (3.29)	2.29 (1.48)	2.63 (1.53)
Old	.70 (.83)	6.39 (3.44)	5.91 (3.54)	3.37 (2.14)	3.68 (2.38)
F	8.59*	2.75	2.36	8.46*	5.82
F after accuracy adjustment	5.80	21.80*	11.63*	21.78*	13.61*
Young > = 75%	.19 (.18)	5.37 (2.15)	5.02 (3.32)	2.47 (1.27)	2.83 (1.51)
Old > = 75%	.71 (.85)	8.65 (3.57)	8.14 (2.56)	4.32 (1.72)	4.24 (.79)
F	8.55*	9.65*	7.67*	15.07*	3.28
Probe recognition accuracy (percentage correct)					
Young	NA	NA	NA	NA	69.4 (19.5)
Old	NA	NA	NA	NA	65.0 (16.7)
F					1.03
F after accuracy adjustment					.98
Young > = 75%	NA	NA	NA	NA	73.3 (17.4)
Old > = 75%	NA	NA	NA	NA	77.8 (17.9)
F					.24

Note. The sample sizes for the analyses restricted to subjects with at least 75% accuracy were 24, 23, 42, 36, and 32, respectively, for young adults in Experiments 1–5, and 23, 8, 10, 11, and 4, respectively, for older adults in Experiments 1–5. NA indicates measures are not available because tasks were not administered.

$^*p < .01$.

(ANCOVA) with decision accuracy as the covariate. The second analysis consisted of contrasting only those subjects in each age group with decision accuracies of at least 75%. Note that both types of analyses are relatively conservative in that minimizing the age difference in one measure may also tend to reduce it in other correlated measures. Furthermore, the analyses with the restricted samples have lower statistical power than the original analyses because of the smaller sample sizes.

Fortunately for ease of interpretation, the various analyses were generally consistent in revealing that young and old adults were fairly similar in the number of unique information requests, but that older adults made more repeated information requests than young adults. This pattern suggests that the two groups did not differ in the amount of necessary information that they obtained (i.e., the unique requests), but did differ in the amount of redundant information requested (i.e., the repeated requests). Because the number of repeated information requests might be considered an indirect reflection of working-memory functioning, these results are consistent with the hypothesis that older adults are less effective than young adults in one aspect of working memory.

To recapitulate, the major findings of Experiments 1–3 were that young adults, in addition to performing more rapidly and more accurately than older adults in the cube comparison task, were significantly superior in three different measures of working memory. They were able to remember more line positions while connecting other lines in the line span task, they exhibited smaller declines in accuracy as the orientation discrepancy between the cubes increased, and they made fewer redundant requests to inspect previously viewed cube faces.

Experiment 4

Although the results across the independent samples of subjects in Experiments 1–3 were quite consistent, they are all based on a single task. It was therefore considered desirable to determine whether certain results, and particularly the finding of age differences in the number of repeated information requests, could be replicated in a different experimental task. The task chosen for this purpose was a computer-administered version of the Raven's Progressive Matrices Test. This test involves the presentation of a 3 × 3 matrix of geometric patterns, with the subject instructed to select the alternative that best fits a missing cell in the matrix. In our computer-administered version of the task, the contents of each matrix cell could be displayed either simultaneously or successively and under control of the subject.

In addition to performing the new computer matrix task, all subjects in this experiment also performed the computer cubes task. This allowed comparisons of the relations between measures of performance in the two tasks.

Method

Subjects

Characteristics of the new samples of 50 young adults and 46 older adults who participated in this experiment are summarized in Table 1.

Experimental Tasks

Computer cubes. — The computer cubes task was similar to that used in Experiments 2 and 3, with two modifications. One modification was that keyboard control replaced the use of the mouse for indicating faces to be examined and for communicating decisions. The cube face to be examined was indicated by typing the number (displayed in the center of each face) of the relevant face, and decisions were communicated by typing the number on the keyboard, followed by the bottom right key (/) for SAME or the bottom left key (Z) for DIFFERENT. The second modification was that, in order to reduce the length of the experimental sessions, the number of information requests was restricted to an arbitrary maximum of 12 per trial. After a total of 12 requests, the subject was required to make a decision and move on to the next trial.

Computer matrix. — Problems in the computer matrix task resembled those in Sets I and II of Raven's Advanced Progressive Matrices (Raven, 1962), with various types of geometric patterns in 8 of the 9 cells of a 3 × 3 matrix. As in the computer cubes task, there were two display formats consisting of simultaneous presentation (contents of all 8 cells visible) and successive presentation (contents of only one cell visible at any given time). Both versions of the task differed from the standard Raven's Progressive Matrices Test, in that the matrix and the answer choices were presented on successive displays. The matrix was displayed until the subject indicated that he or she was ready to make a decision, at which time the eight answer choices were displayed. Once the decision had been made to view the answer choices, the subject was prohibited from viewing the original matrix again.

The particular matrix cell to be examined in the successive condition was indicated by typing the number (which was displayed in the center of each cell) of the relevant cell. Instructions emphasized that accuracy was important, but that the number of matrix cells viewed prior to making a decision should be kept to as few as possible. Decisions in both the simultaneous and successive conditions were communicated by typing the number of the answer choice (displayed immediately above each choice) thought to provide the best completion of the matrix.

Procedure

All subjects performed the simultaneous and successive versions of the computer matrix task followed by the simultaneous and successive versions of the computer cubes task. The number of practice trials was 6 in each condition of the computer matrix task, and 3 in each condition of the computer cubes task. Each experimental block contained 18 trials, with one block in the simultaneous version of each task, and two blocks in the successive version.

Results and Discussion

The pattern of results from the computer cubes task was