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Sources of Age-Related Individual Differences in Block Design Tests

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Three experiments were conducted to investigate the possibility that adult age differences on block design tasks originate at least in part because of a reduced efficiency with increased age in the cognitive processes associated with block manipulation. Young and older adults performed a computer-implemented block design task constructed in such a way that design segmentation and motor dexterity factors were minimized. The older adults, compared to the young adults, were substantially slower and less efficient (in terms of a lower frequency of selecting the optimum sequence of block manipulations to match the target pattern). It was concluded that important sources of age-related individual differences on block design tasks are the speed of carrying out relevant processes, and one's knowledge about the relationship of the patterns on the block's faces to one another.

Block design tests, in which the examinee is required to arrange a set of blocks to reproduce a displayed pattern, represent a puzzle to cognitive psychologists. On the one hand, the correlational evidence suggests that block design tests assess an important aspect of intellectual functioning because performance on these tests is correlated with a number of accepted measures of intelligence. For example, the manual (Wechsler, 1982) for the Wechsler Adult Intelligence Scale-Revised (WAIS-R) reports that the correlation between the score on the Block Design subtest and the corrected composite score from the remaining 10 subtests is .68. On the other hand, block design tests have low face validity as an index of intelligence because the activity of manipulating blocks to reproduce a pattern does not seem to require much in the way of higher-order thought processes.

This apparent paradox is even more bewildering when viewed from the perspective of age differences in adulthood. Many studies have documented rather dramatic age-related declines in Block Design performance (e.g., the data summarized in Figure 4.10 of Salthouse [1982] suggest a decline of about 8% per decade in cross-sectional samples), a phenomenon that some researchers have attributed to the speeded nature of the task. However, Doppelt and Wallace (1955) found that providing extra time had a relatively small effect on the scores of older adults performing the Block Design test, and Storandt (1977) reported that significant age differences between young and old adults were still evident

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even when no time limits were imposed and no bonus points were assigned for rapid completion. Both studies further reported that the correlations between performance in the standard and untimed conditions were quite high, with medians of .94 in the Doppelt and Wallace (1955) study and .87 in the Storandt (1977) study. In a more direct analysis, Royer, Gilmore, and Gruhn (1984) examined age effects on block design performance after subtracting an estimate of each individual's perceptual-motor speed, inferred from the time required to reproduce a solid design, from his or her time required to reproduce the patterned designs. Although this procedure presumably minimized the influence of slow movement processes, very similar age trends to those found with the conventional block design measures were evident in these speed-adjusted scores. These different types of findings, therefore, converge to suggest that, contrary to the speculations of some authors, simple factors of perceptual or motor speed are not responsible for much of the individual differences associated with adult age on the Block Design test.

One means of determining the sources of individual differences on a given task is to formulate a process model of the task to allow systematic investigation of those processes and of the role each plays in overall performance. Somewhat different models of the block design task have been proposed by Royer (1977, 1978, 1984) and Schorr, Bower, and Kiernan (1982), but both include processes involving segmentation of the to-be-reproduced pattern into cells corresponding to individual blocks and manipulation of the blocks to match the segmented cells. The segmentation or pattern-analysis component is likely to be an important source of variance in block design tasks because substantial individual differences have been found in tasks in which patterns have to be analyzed or decomposed to locate or identify simple figures embedded in complex designs. This is particularly true for age-related differences because increased age has consistently been found to be associated with poorer performance on tests such as the Hidden Figures and Embedded Figures tests (e.g., Axelrod & Cohen, 1961; Basowitz & Korchin, 1957; Botwinick & Storandt, 1974; Chown, 1961; Crosson, 1984; Eisner, 1972; Lee & Pollack, 1978; Panek, Barrett, Sterns, & Alexander, 1978; Schwartz & Karp, 1967).

Royer, Gilmore, and Gruhn (1984) have also reported that adults under the age of 30 are less affected by the perceptual cohesiveness of the stimulus designs than adults aged 49 and above. Because more cohesive designs are presumably more difficult to segment than less cohesive designs, this finding is consistent with the view that the efficiency of segmenting decreases with age. This interpretation may have to be qualified to mean the period between young and middle adulthood, however, because these investigators failed to find age-by-cohesiveness interactions among adults ranging from 49 to over 75 years of age.

It is not yet known whether the block manipulation component contributes to variation in block design performance, and if so, whether this is primarily due to differences across individuals in the speed of executing the same manipulations, or to differences in the number or efficiency of the manipulations being executed. If the latter is the case, one might infer that at least some of the variance in block design tasks is due to differences in the quantity or quality of the examinees' block-relevant knowledge. That is, differences in the number of discrete manipulations required to produce a given pattern on the block presumably reflect differences in one's knowledge about the relationship of block faces to one another, and how one configuration of block faces can be transformed into another configuration by appropriate manipulations of the block.

The three studies in the current report were designed to investigate the block-manipulation component of block design performance with a task specially designed to minimize the pattern segmentation component and emphasize cognitive aspects of block manipulation. Subjects included both young and old adults in order to explore the source of the well-documented age differences on block design tasks.

EXPERIMENT 1

A version of the WAIS-R Block Design test was implemented on a computer in such a manner as to minimize the need for segmentation of the to-be-reproduced designs and also reduce the role of motor dexterity factors. The task consisted of a series of displays like that illustrated in Figure 1, in which the subject was instructed to use keypress responses to manipulate the block at the top of the display to reproduce the design in the stimulus matrix on the left in the response matrix on the right. Because the computer monitored all responses, it was possible to conduct detailed analyses of the processes contributing to age-related differences in the time and efficiency of performance on this task.

Method

Subjects. Twenty young adults (ages 18–35 years, mean = 20.2) and 20 older adults (ages 63–77 years, mean = 70.9) participated in a single session of approximately 1.5 hours. There were 15 females and 5 males in each group; the young subjects were recruited from the undergraduate population at the University of Missouri, and the older subjects were recruited from the Columbia, Missouri community. The young adults averaged 13.9 years of formal education (range 12–17), and the older adults averaged 16.9 years (range 12–22). Self-reported health status on a five-point scale (1 = Excellent, 5 = Poor) averaged 1.70 for the young adults and 1.85 for the older adults.

Procedure. All subjects were administered three tasks in the same fixed order: the WAIS-R Digit Symbol Substitution subtest; the WAIS-R Block Design subtest; and the experimental task. Standard administration and scoring procedures were followed with the two WAIS-R subtests.

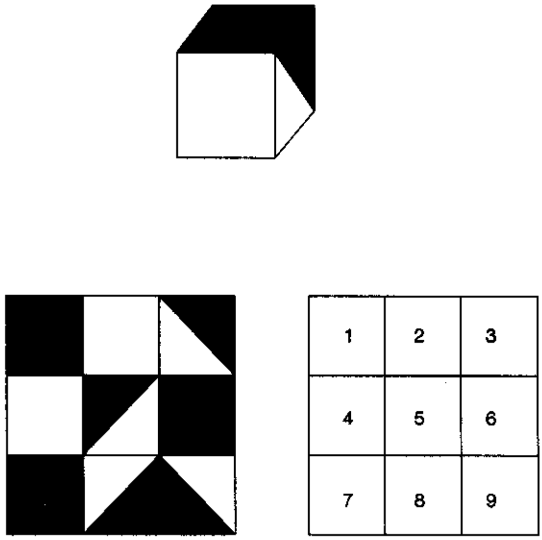

FIG. 1. Illustration of a display at the beginning of a trial in the experimental task used in Experiments 1 and 2.

A total of 40 trials, in two sets of 20, were administered in the experimental task, with two practice trials presented before the first set of test trials. Each trial consisted of a computer-presented display like that illustrated in Figure 1. Notice that the stimulus designs consisted of nine cells, with each cell containing one of six possible patterns (i.e., empty, solid, or diagonal with the solid in one of the four corners). Every stimulus design was different, with no constraints on the number or position of each type of cell pattern except that the resulting design could not be one of those used in the WAIS-R Block Design test.

Each trial required the subject to reproduce the stimulus design in the response matrix by manipulating the block at the top of the display to produce patterns that would match the patterns in each of the target cells. The block could be rotated clockwise in the picture plane by successive presses of the ENTER key on the keyboard, and it could be rotated in the depth plane right, left, up, or down, by pressing the appropriate arrow key on the keyboard.

The front face of the block could be transferred to the appropriate cell in the response matrix by pressing a number from 1–9 on the computer keyboard. As soon as a number was entered the cell in the response matrix corresponding to that number was filled with the pattern from the front face of the block, and the block was randomly rotated to a new configuration of patterns on the front, right, and top faces.

Subjects were instructed to reproduce the stimulus design in the response matrix with the fewest possible manipulations of the blocks, but they were allowed as much time as necessary. Two strategies for performing this task became apparent in pilot research. One was to attempt to match the front face of the block with whatever cell in the matrix was appropriate, and the other was to attempt to manipulate the block to produce the pattern corresponding to each cell in sequence. Because it was difficult to analyze the manipulation processes when subjects were not trying to produce specific block patterns, the instructions indicated that the cells in the response matrix should be completed in sequence.

Results and Discussion

Mean raw scores on the WAIS-R Digit Symbol test were 68.3 (SD = 8.4) for the young adults and 52.1 (SD = 9.8) for the older adults, $t(38) = 5.58$, $p < .01$, which were equivalent to scaled scores of 12 and 15, respectively. Scores on the WAIS-R Block Design test averaged 40.0 (SD = 7.4) for young adults and 28.7 (SD = 5.6) for older adults, $t(38) = 5.41$, $p < .01$, which corresponded to scaled scores of 12 and 13, respectively. These results are similar to those from many previous studies and thus indicate that the present samples were probably fairly representative of their age groups, although both were somewhat above average in these measures of intelligence (i.e., the scaled scores average 10.0 for the standardization sample in the WAIS-R).

The primary dependent variables in the experimental task were the average number of seconds per trial to represent performance time, and the average number of block manipulations per trial as a measure of performance efficiency. Accuracy of pattern matching averaged greater than 98% correct cells in both age groups and was not considered further.

Older adults were significantly slower and less efficient than young adults. The average time per trial was 68.41 s (SD = 14.49) for young adults, and 119.83 s (SD = 34.00) for older adults; $t(38) = 6.22$, $p < .01$. Young adults averaged 15.29 (SD = 1.86) block manipulations per trial compared to 19.10 (SD = 5.22) for older adults; $t(38) = 3.07$, $p < .01$. Both performance measures were significantly correlated with scores on the WAIS-R Block Design test as the correlations were −.59 ($p < .01$) for time, and −.42 ($p < .01$) for efficiency. Partial correlations controlling for age were −.25 for time and −.21 for efficiency, suggesting that at least some of this relationship is attributable to the variable of age.

Examination of the records of each subject's pattern of block manipulations led to a more detailed analysis of the efficiency of manipulating the blocks. This analysis was based on a categorization of each combination of initial block configuration and target cell pattern with respect to the minimum number of block manipulations required to produce the pattern on the front face of the block. These categorizations can be illustrated by referring to Figure 1.

The simplest category was termed 0-Minimum because the target pattern was identical to the front face of the block, and hence, no manipulations of the block were required to produce a match. Cell 2 of the stimulus matrix in Figure 1 would be an exemplar of this category, because no block manipulations were required to produce the pattern in this cell on the front face of the displayed configuration of the block. The most complex category, referred to as 2-Minimum, consisted of situations in which two manipulations of the block were required to match the target pattern. Cell 9 of the stimulus matrix illustrates this category, because with the displayed block configuration, at least two distinct manipulations (e.g., rotate up and then rotate right) would be necessary to produce the target pattern on the block's front face.

Two separate categories of situations were distinguished when the pattern could be matched with a minimum of one manipulation of the block—one corresponding to block configurations in which the target pattern was visible as the top or right face of the block, and the other in which the target pattern was hidden on either the left or bottom face of the block. Cells 1 and 3 with the displayed block configuration are both examples of the 1-Visible category because the target pattern can be matched by either rotating the block down to bring the top face to the front (for Cell 1), or by rotating the block left to bring the right face to the front (for Cell 3). An example of the 1-Invisible category with the displayed block configuration is Cell 5 because the target pattern could be produced by rotating the block to the right to bring the face currently hidden on the left side of the block to the front.

The next step in the analysis of manipulation efficiency consisted of computing, for every subject, the percentage of occurrences in each category in which the minimum number of manipulations were actually executed to produce a match between the target pattern and the front face of the block. In other words, the percentage of 0-Minimum category situations in which exactly 0 manipulations were carried out before matching the pattern was determined, as was the percentage of 1-Visible situations in which exactly 1 manipulation was carried out before placement of the pattern, and so forth.

Although each of these percentages was computed in a similar manner, they can be interpreted as indexing quite distinct aspects of processing. For example, the percentage of minimum manipulations in the 0-Minimum category presumably reflects accuracy of simple pattern recognition processes because no manipulations are required to produce the target pattern, and the subject needs only to determine whether the patterns match before making the cell assignment. Because the target patterns are visible in the block configuration in the 1-Visible category and only require an obvious down or left rotation of the block, the measure in this category can be viewed as an index of the breadth of the subject's attention during the task. That is, as long as the subject attends to the right and top faces of the block in addition to the front face, the percentage of 1-Visible occurrences with only one manipulation prior to cell assignment should be quite high because the appropriate manipulation is apparent from the configuration of patterns on the block.

Finally, the percentages of minimum manipulations in the 1-Invisible and 2-

Minimum categories can be interpreted as reflecting the quality and completeness of the subject's internal representation of the three-dimensional block because knowledge of the hidden faces of the block is presumably necessary to achieve the minimum number of moves when the target pattern is not visible in the displayed block configuration.

The correlations of these variables with WAIS-R Block Design score and the efficiency measure of the average number of manipulations in the experimental task are displayed in Table 1. The correlations with WAIS-R Block Design scores indicate that higher scores on the task are associated with better-quality internal representations of the three-dimensional blocks used in the task. The correlation between the percentage of minimum manipulations in the 1-Visible category and the efficiency measure in the experimental task suggests that more efficient subjects not only have better-quality representations of the blocks, but also may have a broader focus of attention to all block faces while performing the task.

Similar trends for the young adults to have higher percentages than the older adults were evident in each category; but due to the large variability, the age differences were significant only in the measures assumed to reflect breadth of attention during processing and quality of the internal representation of the three-dimensional block.

Detailed analyses of individual differences in time of performing the experimental task were conducted by application of a simple process model that distinguished among five theoretical processes. These processes were: (1) *Encode* the pattern in the target cell; (2) Encode the front face of the block, *Compare* it with the target pattern, and place the block in the response matrix if they match; (3) *Manipulate* the block to produce a new pattern in the front face; (4) *Access* or generate an internal representation of the block to visualize the hidden faces; and (5) *Plan* a sequence of two or more manipulations to produce the desired pattern.

TABLE 1
Summary Statistics for the Detailed Measures of Manipulation Efficiency, Experiment 1

	Correlation with:				Means (in Percentages)				
	WAIS-R BD		# Moves		Young		Old		
Category									t(38)
0-Min.	.21	(.06)	.00	(.12)	98.2	(1.8)	91.6	(19.7)	.48
1-Vis.	.30	(.06)	−.36*	(−.23)	96.1	(2.9)	83.5	(23.2)	2.42*
1-Invis.	.43**	(.36*)	−.50**	(−.45*)	53.0	(21.0)	42.4	(20.9)	1.61
2-Min.	.33*	(.18)	−.46**	(−.38*)	38.2	(15.3)	29.6	(9.7)	2.11*

*$p < .05$
**$p < .01$
Note: Values in parentheses in the correlation columns are correlations partialling out age, and values in parentheses in the means column are standard deviations.

Duration estimates of these five processes were derived in the following manner. First, the median time to assign the front face of a block to a cell in the response matrix was determined for all assignments preceded by one or more manipulations of the block. This value served as the estimate of the *Compare* duration because it represented the time to encode the block face, compare it with the target pattern, and make the appropriate placement in the response matrix. The *compare* duration was subtracted from the median time to make a cell assignment when there were no prior block manipulations to yield an estimate of the duration of the *Encode* process. It was assumed that the major difference between the durations of the cell assignments when preceded or not preceded by prior manipulations of the block was that no encoding of the target pattern was necessary in the former case (because it had already been completed at a prior manipulation), and thus, the difference between the two durations should provide a measure of the added (i.e., encode target pattern) process.

The duration of the *Manipulate* process was estimated from the median time to manipulate the block when the subject used only one rotation to match the target pattern in the 1-Visible condition. This is presumably the purest case of manipulation processes because only one manipulation is required, and the presence of the target pattern on one of the visible faces of the block makes the nature of that manipulation unambiguous.

Estimates of the durations of the remaining two processes were derived by subtracting two manipulation times—that in the 1-Visible from that in the 1-Invisible to provide an estimate of the *Access* process, and that in the 1-Invisible from that in the 2-Minimum to provide an estimate of the *Plan* process. The former yields an indication of the added time to generate or access an internal representation of the hidden faces of the block prior to the manipulation, and the latter supplies an estimate of the additional time needed to plan a sequence of two or more block manipulations.

Summary statistics for the parameters described above are illustrated in Table 2. The values in this table represent the means across subjects of the medians (or differences between medians) of the most efficient occurrences within each category. In other words, only the times for single-manipulation responses in the 1-Visible category were used in the computation of that median, only the times in two-manipulation responses in the 2-Minimum category were used in the computation of that median, and so forth. This procedure has the advantage of ensuring that all measurements reflect processing during conditions of optimum efficiency.

Note that the *Compare* duration was significantly correlated with WAIS-R Block Design score, indicating that people who were fast at encoding and comparing the block face tended to have higher scores on the standard Block Design test than people slower at that process. All durations except that for the *Encode* process were significantly correlated with average time per trial in the experimental task.

TABLE 2
Summary Statistics for the Detailed Measures of Performance Time, Experiment 1

	Correlation with:				Means (in Msec)				
	WAIS-R Block Design		Avg. Time						
Variable					Young		Old		t(38)
Encode	−.06	(.03)	.14	(.06)	1055	(235)	1182	(557)	0.94
Compare	−.66**	(−.38)	.79**	(.60**)	1762	(321)	2878	(786)	5.88**
Manip.	−.45**	(−.12)	.80**	(.69**)	3041	(250)	4452	(1479)	4.20**
Access	.06	(.18)	.42**	(.49**)	531	(995)	767	(1529)	0.58
Plan	−.06	(−.02)	.48**	(.60**)	586	(1863)	989	(3966)	0.41

*p < .05
**p < .01
Note: Values in parentheses in the correlation columns are correlations partialling out age, and values in parentheses in the means column are standard deviations.

Young adults averaged between 59% and 69% of the time of older adults in the durations of all processes except *Encode* (for which the average of the young adults was 89.3% of the older adults). However, because of the large variability, only the differences with the *Compare* and *Manipulate* processes were significant. A recent review by Salthouse (1985) indicates that proportional differences of this magnitude are fairly typical in contrasts of measures of speeded performance among young and old adults.

EXPERIMENT 2

One of the most intriguing findings from Experiment 1 is the discovery that the measures postulated to reflect block knowledge (i.e., the percentage of minimum manipulations in the 1-Invisible and 2-Minimum categories) were significantly correlated with manipulation efficiency, and tended to be greater among high scorers on the WAIS-R Block Design test. These results led to the speculation that performance on the experimental task might improve substantially with additional experience that provides an opportunity for the acquisition of further knowledge about the relationships among patterns on different faces of the block. This hypothesis is of particular interest with respect to the age differences on the experimental task because the pattern of results displayed in Table 1 is consistent with the view that older adults perform poorly in this task when compared to young adults, at least in part because of inadequate internal representations of the to-be-manipulated blocks. In order to determine the specificity of the knowledge acquired with experience about the task and the block, subjects were administered a transfer condition involving a new arrangement of patterns on the faces of the block.

Method

Subjects. Ten young adults (ages 20–23 years, M = 20.9) and 10 older adults (ages 61–77 years, M = 66.3) participated in three sessions of approximately 1.5 hours each over a period of approximately one week. There were 6 females and 4 males in each group. The young adults averaged 15.0 years of formal education (range 14–17), and the older adults averaged 16.9 years (range 12–21). Self-reported health status on a five-point scale (1 = Excellent, 5 = Poor) averaged 1.70 for both groups.

Procedure. One stimulus block was used during training and a different one during transfer, with one-half of the subjects in each group receiving the first stimulus block during training and the second stimulus block during transfer, and vice-versa for the other half. One of the stimulus blocks was identical to that used in Experiment 1 (and that employed in the WAIS-R Block Design test), and the other was created by rearranging the patterns on different faces of the block.

The procedure in the first session was identical to that of Experiment 1, with the administration of the WAIS-R Digit Symbol and Block Design subtests followed by 40 experimental trials. An additional 80 experimental trials were presented in the second session, and still another 40 experimental trials in the third session. At the end of the training trials in the third session, a set of 20 transfer trials was presented with the new stimulus block.

Results and Discussion

Mean raw scores on the WAIS-R Digit Symbol test were 64.4 (SD = 18.8, scaled score = 11) for the young adults, and 51.4 (SD = 12.4, scaled score = 13) for the older adults. Scores on the WAIS-R Block Design test averaged 39.4 (SD = 7.0, scaled score = 12) for the young adults, and 32.9 (SD = 10.9, scaled score = 14) for the older adults. As was the case in Experiment 1, these data again suggest that the samples, and particularly the older adults, were above average in these aspects of intelligence, but otherwise, were fairly representative of their age groups.

Summary measures of performance for the two age groups across successive sets of 40 trials are displayed in Table 3. Accuracy of design reproduction is not portrayed because average accuracy exceeded 99% for both groups at every stage of practice.

It is noteworthy that the age differences in the time and efficiency measures displayed in Table 3 were not statistically significant. These results contrast with those of Experiment 1, and are probably due to a combination of lower statistical power attributable to smaller sample sizes, and a somewhat anomalous sample of young adults in one of the experiments. The older adults in the two experiments performed equivalently in the initial session, both with respect to the time measure, that is, 119.83 s in Experiment 1 vs. 115.90 s in Experiment 2, $t(28)$ =

TABLE 3
Effects of Practice on the Performance Variables in Experiment 2

Variable	Successive 40 trials 1	2	3	4	AGE (1,18)	PRACT. (3,54)	AGE X PRACT. (3,54)
Time (Average sec per trial)							
Young	95.99	72.29	66.27	60.38	3.53	25.99**	0.03
Old	115.90	92.72	84.13	79.17			
Efficiency (Average number of block manipulations per trial)							
Young	22.7	17.8	17.6	16.4	0.10	10.21**	0.94
Old	20.0	18.3	17.2	15.9			
0-Minimum (Percentage with minimum number of block manipulations)							
Young	98.9	98.9	100.0	99.9	4.01	0.64	0.89
Old	96.9	97.9	94.6	99.0			
1-Visible (Percentage with minimum number of block manipulations)							
Young	92.6	97.0	97.6	98.0	3.86	5.61**	0.71
Old	86.8	92.3	93.6	97.8			
1-Invisible (Percentage with minimum number of block manipulations)							
Young	49.8	59.0	65.5	64.7	4.01	5.82**	2.41
Old	40.1	40.0	44.4	42.2			
2-Minimum (Percentage with minimum number of block manipulations)							
Young	41.1	44.4	47.2	48.5	0.00	3.03*	0.05
Old	39.9	45.1	47.3	47.6			
Encode (msec)							
Young	1376	1527	1559	1613	4.40	0.73	1.02
Old	1202	1118	1225	1167			
Compare (msec)							
Young	1828	1230	1037	877	12.59**	38.39**	0.53
Old	2741	2246	2030	2004			
Manipulate (msec)							
Young	3510	3201	3049	3026	4.68*	5.56**	0.40
Old	4307	3662	3525	3529			
Access (msec)							
Young	394	283	287	134	2.09	2.03	0.77
Old	807	442	304	465			
Plan (msec)							
Young	468	507	505	559	−4.61*	1.47	1.15
Old	−240	−141	−255	−4			

*$p < .05$
**$p < .01$

0.24, and the efficiency measure, that is, 19.10 manipulations per trial in Experiment 1 versus 20.00 in Experiment 2, $t(28) = 0.42$. However, the young adults in the present experiment were substantially slower than those in the first experiment, that is, 95.99 s in Experiment 2 versus 68.41 s in Experiment 1, $t(28) = 2.39$, $p < .05$, and were also somewhat less efficient, that is, 22.68 versus 15.29 manipulations per trial, $t(28) = 1.97$, $p < .10$.

Despite the lack of significant age differences in the overall measures of time and efficiency, the trends in the detailed measures of time and efficiency were, with one exception, similar to those of Experiment 1. The exception was the *plan* measure in which estimates of negative durations for the older adults resulted in a significant age difference in the opposite direction from that expected on the basis of Experiment 1. The negative duration estimates resulted because a number of the older adults responded much faster in their initial block manipulation in the 2-Minimum condition than in the 1-Invisible condition.

The results summarized in Table 3 indicate that practice resulted in significant improvements of most variables, particularly those exhibiting the largest correlations with WAIS-R Block Design performance in Experiment 1 and for which the age differences were largest. This outcome is clearly consistent with the interpretation that block knowledge, which can be expanded with relevant experience, is an important factor in performance on the block design test. However, it is important to note that none of the Age × Practice interactions were significant, and the only variable with a trend toward a significant interaction (i.e., 1-Invisible) exhibited a pattern in which young adults improved more with practice than did the older adults.

Examination of performance on the transfer task allowed a determination of the specificity of the knowledge acquired with experience on the task. Because only 20 trials were administered with the new block, estimates of the process durations were very unstable, and thus, they were not examined in this context. All of the remaining measures were so analyzed, however, and the mean difference scores created by subtracting the measure in the last training session from the measure in the transfer session are summarized in Table 4.

The most important results in Table 4 are that both the time and the number of

TABLE 4
Mean Changes in Performance During Transfer (Post - Pre), Experiment 2

Variable	Young	Old	t(18)	Both	t(19)
Time	4.35	5.72	0.36	5.04	2.71*
Efficiency	1.59	2.36	0.77	1.97	3.99**
0-Minimum	−0.5	0.7	−1.47	0.1	−0.20
1-Visible	0.2	−1.4	0.85	−0.7	0.69
1-Invisible	−16.9	−13.5	0.28	−15.2	2.57*
2-Minimum	−9.5	−5.3	0.44	−7.4	1.59

*$p < .05$
**$p < .01$
Note: The t-values in the fourth column are based on the contrast between young and old adults, while those in the sixth column evaluate the significance of the difference scores for the combined sample of young and older adults.

manipulations required to reproduce the designs increased when the subjects were transferred to a new and unfamiliar block. Furthermore, the detailed analyses indicate that the greater number of manipulations is primarily due to reduced efficiency when the target pattern is not visible in the displayed configuration of block faces.

EXPERIMENT 3

The purpose of the third experiment was to determine whether the results of the previous experiments could be replicated with a different mode of response and a simpler display of the target pattern. An experimental trial in this modified task consisted of the same type of block presentation as in the earlier experiments, but the target pattern was illustrated in a single square at the bottom of the display. Between the block and the target was a list of possible response alternatives from which the subject was instructed to make his or her choice.

Method

Subjects. Twenty-seven young males (ages 18–24 years, $M = 19.7$) and 20 older males (ages 55–68 years, $M = 61.0$) participated in a single session of approximately 1.5 hours. The young subjects were all undergraduates at Georgia Institute of Technology (13.8 mean years of education), and the older subjects were all alumni of Georgia Institute of Technology (16.7 mean years of education). Self-reported health status on a five-point scale averaged 1.20 for the young adults and 2.05 for the older adults.

Procedure. All subjects were administered four tasks in the same fixed order: the WAIS-R Digit Symbol Substitution subtest; the WAIS-R Block Design subtest; and two versions of the experimental task. Standard administration and scoring procedures were followed with the two WAIS-R tasks.

Each experimental task involved a single set of 50 trials, with each trial consisting of a display of block like that illustrated in Figure 1, a menu of possible responses, and a single target pattern. The target pattern never matched the front face of the block, but it was equally likely to match a visible (right or top) or invisible (bottom, back, or left) face of the block. Alternatives represented in the response menu consisted of left, right, up, and down movements plus all possible pairs of these movements. The subject entered his choice by typing the number corresponding to the desired sequence of manipulations, at which time the block configuration resulting from this sequence was displayed and a feedback signal was presented. An unlimited time was allowed for response selection, and no attempt was made to hurry the decisions nor, partly for this reason, to monitor the time taken to reach the decision.

The block used in the first version of the experimental task was identical to the blocks in the WAIS-R Block Design test. The alternative block employed in Experiment 2, consisting of a different arrangement of patterns on the various faces of the block, was used in the version of the experimental task in the second set of trials.

Results

Mean raw scores on the WAIS-R Digit Symbol test were 64.9 (SD = 11.1, scaled score = 11) for the young adults, and 55.4 (SD = 6.5, scaled score = 12) for the older adults, $t(45) = 3.42, p < .01$. Scores on the WAIS-R Block Design test averaged 41.9 (SD = 7.0, scaled score = 13) for the young adults and 34.5 (SD = 5.3, scaled score = 13) for the older adults, $t(45) = 3.99, p < .01$. As in the previous experiments, these results suggest that the present samples were somewhat select members of their age groups but, otherwise, were generally similar to those used in many previous studies of cognitive aging.

The dependent variable in the experimental tasks was the percentage of trials in which the subject selected the most efficient response alternative to produce the target pattern on the front face of the block. These values were grouped according to the relationship between the block configuration and the target pattern, and then averages computed across the subjects in each age group. Means of these values and the correlations of the measure with performance on the WAIS-R Block Design subtest are displayed in Table 5.

The results in Table 5 indicate that the major findings of Experiment 1 are replicated in this study. As was found earlier, performance in the WAIS-R Block Design test is correlated with the measures indexing quality of block knowledge, and young adults score higher on these measures than older adults. However,

TABLE 5
Summary Statistics for the Measure of Manipulation Efficiency, Experiment 3

	WAIS-R BD		Means (in Percentages)				
	Correlation		Young		Old		t(45)
Normal Block							
1-Vis.	.14	(.15)	93.5	(11.6)	92.8	(9.5)	0.22
1-Invis.	.53**	(.39**)	84.3	(14.6)	64.8	(25.6)	3.31**
2-Min.	.52**	(.39**)	54.2	(24.4)	32.8	(21.8)	3.10**
New Block							
1-Vis.	.05	(.15)	95.0	(7.3)	97.1	(3.9)	−1.16
1-Invis.	.55**	(.42**)	29.4	(17.0)	14.7	(12.4)	3.25**
2-Min.	.42**	(.24)	58.5	(18.7)	39.0	(18.9)	3.52**

*p < .05
**p < .01
Note: Values in parentheses in the correlation columns are correlations partialling out age, and values in parentheses in the means column are standard deviations.

these results represent more than merely a replication because the discovery that similar results are evident, even when the display consists of a single target pattern and the block manipulation is carried out by means of a single discrete response, suggests that the basic phenomenon is relatively independent of factors related to display segmentation and response manipulation. Moreover, very similar patterns of age differences and relationships with WAIS-R Block Design performance were apparent with the novel block not used in the WAIS-R Block Design task, and thus, the phenomenon is not restricted to a particular, relatively familiar, configuration of patterns on the block. It is also noteworthy that the samples of young and old adults in this experiment were much more homogeneous than those in the previous experiments, and thus, the earlier results cannot be attributed to some type of artifact of heterogeneous samples of research participants.

There is, however, one potentially important difference between the results of Experiment 1 and those of this experiment. This concerns the existence of age differences in the 1-Visible measure postulated to reflect breadth of attention. The fact that young and old adults did not differ on this measure in the current study, despite an identical block configuration to that of Experiment 1, casts doubt on the original interpretation. An alternative interpretation, consistent with the elimination of the age effects on this measure when the mode of manipulating the block was altered from Experiment 1 to Experiment 3, is that this measure primarily reflects one's facility of using keypress responses to manipulate the block. That is, the age differences in this measure in Experiment 1 may simply have indicated that the older adults had greater difficulty than the young adults in using the designated keys to manipulate the block, and these differences were no longer evident when the task was changed to minimize this aspect of the task.

GENERAL DISCUSSION

The experimental task used in these studies was designed to assess the block manipulation aspect of block design performance by minimizing the role of the design segmentation component and reducing motor dexterity factors by having the manipulations carried out with simple keypresses on a computer keyboard. Although time was measured in two of the experiments, subjects were allowed as much time as they desired to perform the task. It was, therefore, possible to distinguish between variations in the time to select or execute the same block manipulations and variations in time associated with carrying out more or different manipulations. The major results were that there were substantial age-related differences in both the time and efficiency measures of performance, and that both measures were significantly correlated with score on the WAIS-R Block Design task.

Manipulation efficiency was decomposed into three aspects corresponding to pattern recognition, breadth of attention or ease of keyboard control, and block knowledge as exemplified in the quality of the internal representation of the block. Older adults were somewhat poorer than young adults in each aspect, but breadth of attention/keyboard control (indexed by the percentage of minimum manipulations in the 1-Visible category) and block knowledge (indexed by the percentage of minimum manipulations in the 1-Invisible and 2-Minimum categories) accounted for the greatest proportions of variance in WAIS-R Block Design performance (Experiments 1 and 3) and manipulation efficiency in the experimental task (Experiment 1). These are also the aspects of efficiency that exhibited the greatest improvements with practice (Experiment 2), suggesting that effective deployment of attention (or appropriate control of relevant keystroke commands), and complete and accurate internal representations of the manipulated block are important determinants of both initial performance and magnitude of improvement on this task. The finding that the largest transfer effects in Experiment 2 were evident with the measures of block knowledge is also consistent with the view that subjects improve on the task, at least in part, because they are learning information specific to a particular block.

Time to reproduce the stimulus designs was also analyzed into a number of theoretically distinct aspects or processes (Experiments 1 and 2). The processes corresponding to comparing the block pattern, manipulating the block, accessing an internal representation of the block, and planning a sequence of manipulations were all found to be related to average time per trial on the experimental task, and the first two processes were also significantly correlated with WAIS-R Block Design performance. The largest age differences and the greatest improvements with practice were also evident with the measures used to estimate the durations of the *compare* and *manipulate* processes.

Although not exhibiting significant age and practice effects in Experiment 2, the process concerned with accessing the internal representation to determine the patterns on the hidden faces of the block was also important because the proportional differences across age groups and levels of practice were as large or larger with this variable as with the *compare* and *manipulate* variables.

What can now be said about the sources of age-related individual differences in block design performance? Although these experiments did not test the design-segmentation component, the evidence reviewed earlier suggests that it is probably an important factor in the age differences, at least between young adulthood and middle age. Some of the age differences in standard block design tests may also be due to age-related restrictions in manual dexterity that hamper physical manipulation of the blocks, and the imposition of time limits and the awarding of bonus points for rapid performance also serve to differentially penalize older adults because they are slower than young adults in most activities (cf., Salthouse, 1985).

However, the results of the current experiments indicate that another major source of age differences in block design tasks is the accuracy or completeness of one's internal representation of the to-be-manipulated block. Because the experimental task in these studies required that the block be manipulated to match the target pattern, rather than merely selecting a block with the desired pattern from among a set of randomly arranged blocks, it is possible that this aspect of processing was emphasized more here than in the standard block design task. Moreover, this difference in emphasis may account for the failure to find significant relations between WAIS-R Block Design performance and durations of the *plan* and *access* components in Experiment 1. Regardless of the relative emphases in the two tasks, however, the discovery of significant correlations between WAIS-R Block Design performance and the measures indexing the individual's knowledge of the hidden faces of the block suggests that the fidelity of one's internal representation of the block contributes to efficient performance in block design tasks.

The inference that factors related to the quality of an internal representation are important in the age differences in the block design task is similar to conclusions reached earlier in analyses of age differences in series completion (Salthouse & Prill, in press) and mental synthesis (Salthouse, in press) tasks. Difficulties in establishing and maintaining adequate internal representations of relevant task features may, therefore, be a common thread unifying what have previously been considered unrelated phenomena in the field of cognitive aging.

Although there were pronounced age differences in many of the detailed measures of time and manipulation efficiency, it is interesting that old adults appeared to improve with practice as rapidly as young adults, and they also exhibited comparable patterns of transfer to the new block. While these findings do not necessarily indicate that the age differences can be remediated with practice, they do suggest that important determinants of performance on block design tests can be developed or refined with relevant experience. It remains to be determined whether the types of age-related declines commonly reported on block design tests could be prevented or retarded if that experience could be made available periodically throughout one's adult life.

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