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Age and Experience Effects in Spatial Visualization

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Three studies were conducted to investigate effects related to age and experience on measures of spatial visualization ability. All research participants were college-educated men; those in the experienced group were practicing or recently retired architects. The major results of the studies were (a) that increased age was found to be associated with lower levels of performance on several tests of spatial visualization and (b) that this was true both for unselected adults and for adults with extensive spatial visualization experience. These findings seem to suggest that age-related effects in some aspects of cognitive functioning may be independent of experiential influences.

An important hypothesis concerning the effects of adult age on cognitive functioning attributes the poorer performance of older adults to their lack of recent experience with relevant cognitive abilities. Perhaps the clearest statements of this disuse perspective were by early researchers (e.g., Sorenson, 1933, 1938; Thorndike, Bregman, Tilton, & Woodyard, 1928), but some version of the disuse hypothesis is implicit in the writings of many contemporary researchers (e.g., Ratner, Schell, Crimmins, Mittelman, & Baldinelli, 1987; Willis, 1987). As an illustration of the commitment to this perspective, Kirasic and Allen (1985), in a recent review of research on age and spatial ability, stated as an assertion rather than an hypothesis, that

> A substantial difference . . . [exists] between elderly adults' proficiency outside the psychological laboratory and their proficiency in performing tasks bearing an apparent relationship to their lives outside that setting . . . [and that] age-related performance decrements are more likely to appear on novel tasks or those involving unfamiliar stimuli or settings than on familiar tasks or those involving well-known stimuli or settings. (p. 199)

Despite considerable intuitive appeal and apparent widespread implicit acceptance, there is still very little evidence directly relevant to the disuse hypothesis of age-related cognitive decline. The studies in the current article were designed to investigate this hypothesis by examining the effects of age, experience, and the interrelations of age and experience on spatial visualization ability. *Spatial visualization,* as the term is used here, refers to the mental manipulation of spatial information to determine how a given spatial configuration would appear if portions of that configuration were to be rotated, folded, repositioned, or otherwise transformed. This construct has been identified in a number of factor-analytic studies (e.g., see Lohman, 1988, for a review), and has been found to have predictive validity for success in courses in geometry, drafting, and design (e.g., see reviews in Lohman, Pellegrino, Alderton, & Regian, 1987; McGee, 1979; Smith, 1964).

The purpose of Study 1 in the current project was to determine the nature of the age-related effects on spatial visualization ability within a sample of relatively homogeneous adults. The goal in Study 2 was to investigate possible differences in spatial visualization performance between groups of older adults presumed to vary in the amount of occupational experience requiring spatial visualization abilities. Study 3 involved an examination of the age-related trends in measures of spatial visualization among adults postulated to have continuous and extensive occupational experience using spatial visualization abilities.

Both Studies 1 and 2 involved the same psychometric tests and experimental tasks as those recently used in a study with 50 young adults (Salthouse, Babcock, Mitchell, Palmon, & Skovronek, in press). The current studies capitalized on this commonality by expressing all of the results in terms of standard deviation units of the young adults from the earlier study. This rescaling of the performance measures has the advantage of providing an intrinsically meaningful age comparison by indicating the region in the distribution of young adults in which the performance of the average member in each of the samples in Studies 1 and 2 would be located.

Study 1

As noted earlier, the major purpose of Study 1 was to examine what, if any, age-related trends in spatial visualization performance existed among a sample of adults ranging in age from 20 to 70. The sample can be characterized as relatively homogeneous because all of the participants were male alumni of a university with a primarily technically oriented curriculum, although they were currently engaged in a variety of different occupations.

The four tests of spatial visualization administered in this study, and illustrated in Figure 1, were from the Ekstrom, French, Harman, and Dermen (1976) Kit of Cognitive Reference Tests. It can be seen that the Form Board Test consists of a target shape and several smaller forms; examinees are requested to determine which combination of shaded forms can be assembled to fill the target shape. The Paper Folding Test consists of

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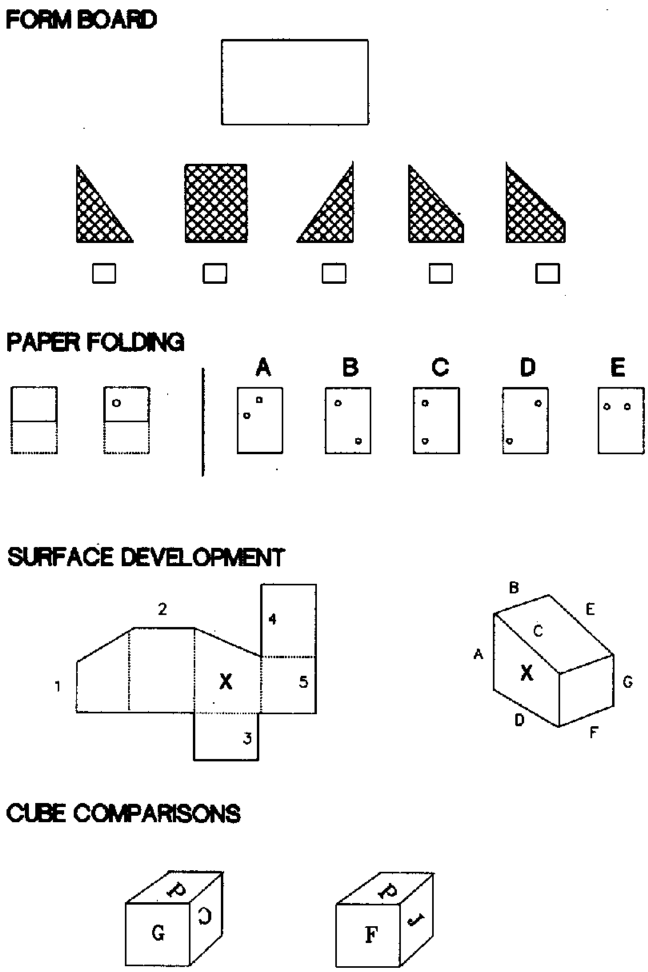

Figure 1. Illustration of types of problems in the four psychometric spatial visualization tests.

a series of illustrations representing a piece of paper undergoing a succession of folds, and then a hole punched through the folded paper. The task for the examinee is to determine which pattern of holes would result from the preceding sequence of folds and punch location. In the Surface Development Test, the examinee is asked to assemble the flat surface on the left into the three-dimensional object on the right, and then to determine the correspondence between letters from the three-dimensional object and numbers from the flat surface. And finally, in the Cube Comparisons Test decisions are to be made concerning whether the two configurations could represent the same cube.

Method

Subjects. Research participants consisted of 50 men between 24 and 67 years of age, with 10 in each decade from 20 to 70 (M = 44.8 years, SD = 13.6). All were alumni of the Georgia Institute of Technology. The mean years of education was 17.0 (age correlation = −.16), and mean health status on a self-rating scale from *excellent* (1) to *poor* (5) was 1.3 (age correlation = .07).

Procedure. Each of the four tests consisted of two separately timed parts, with time limits for each part of 3 min for Paper Folding (10 items), 6 min of Surface Development (30 items), 8 min of Form Board (24 items), and 3 min of Cube Comparisons (21 items). The two parts of each test were administered in immediate succession, with the tests presented in the same sequence (i.e., Paper Folding, Cube Comparisons, Surface Development, and Form Board) for all of the participants.

Results and Discussion

All of the tests were scored in terms of the number of items answered correctly in the allotted time, and scores on the two parts were averaged to provide a single performance measure on each test. Estimates of the reliability of each test, derived by using the Spearman-Brown formula to boost the correlation between the scores on the two parts, ranged from .82 to .89. Correlations among the measures from different tests were all significant ($p < .01$), and ranged from .49 to .71.

The next step in the analysis consisted of converting each participant's score on each test into standard deviation units based on the relevant performance distribution of the sample of 50 young adults (mean age 19.9 years) in Study 1 of Salthouse et al. (in press). These standard deviation scores were then entered into regression analyses, with chronological age as the predictor variable. Results of these analyses, in terms of the linear correlation coefficients and regression lines relating age to performance, are illustrated in Figure 2.

All of the age correlations were negative, and only that with Form Board score was not significant at $p < .01$. In each test, performance was very similar in the decade of the 20s to that of the standardization group of young adults, but it declined about 0.3 SD units per decade through the decade of the 60s. As would be expected from the results of each variable, the same pattern (i.e., an age slope of −.28 SD units per decade, $p < .01$) was evident with a composite measure based on the average of the four standard deviation scores. These results therefore indicate that there appear to be moderately pronounced age-related effects on measures of spatial visualization ability, with adults

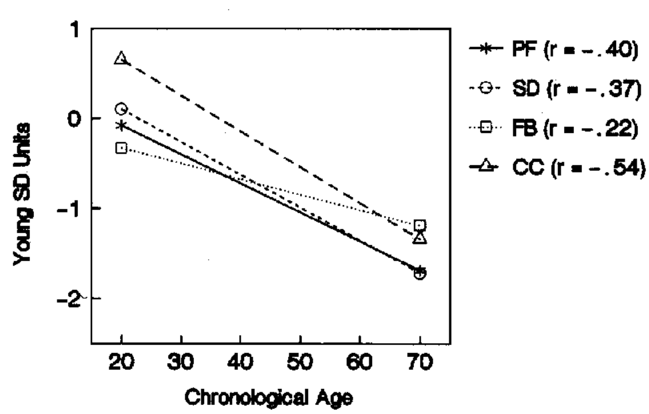

Figure 2. Regression lines indicating the relationship between age and performance for four psychometric tests of spatial visualization in Study 1. (PF = Paper Folding Test; SD = Surface Development Test; FB = Form Board Test; and CC = Cube Comparisons Test. The performance axis in Figure 2 represents the scores scaled in standard deviation units from the relevant performance distribution of 50 young adults in Salthouse, Babcock, Mitchell, Palmon, & Skovronek, in press.)

in their 60s performing between 1.0 and 2.0 *SD* units below the level of adults in their 20s.

Study 2

The goal of Study 2 was to compare two groups of older adults assumed to vary in amount of spatial visualization experience in detailed measures of spatial visualization performance. One of the groups consisted of unselected adults, and the other was composed of currently active or recently retired architects. The contrast between these two groups was considered informative because architects are individuals for whom spatial visualization abilities are presumably in continuous use by virtue of the nature of their occupation. That is, spatial abilities are needed by architects to be able to interpret, and occasionally produce, two-dimensional drawings of three-dimensional structures. It was therefore expected that if continuous and extensive experience can retard or prevent age-related declines that would otherwise occur, then the performance of the architects should be much more similar to that of young adults than to that of their age peers with lesser amounts of relevant experience.

All of the participants were administered a battery of specially designed computer-controlled tasks—in addition to the four paper-and-pencil tests used in Study 1—across five separate testing sessions. The computer-controlled tasks had two advantages over the paper-and-pencil tasks. One was that by presenting each item individually, it was possible to obtain separate measures of both the time and accuracy of the decisions, rather than relying on a single score reflecting an unknown mixture of the two aspects of performance. The second advantage of the computer-controlled tasks was that they allowed systematic manipulation of the number of required spatial transformations (e.g., folds, rotations, and integrations) in each task. This in turn permitted the investigation of possible group differences in the efficiency or effectiveness of transformations by determining whether the accuracy or time differences between the unselected and experienced adults increased as the number of required transformations increased.

Method

Subjects. The unselected and architect groups each consisted of 10 men who were comparable in age (both ranges from 60 to 78, $M = 67.3$ years for unselected, 68.7 years for architects), years of formal education (unselected = 16.3 years, architects = 17.3), and self-reported health status (unselected = 1.5, architects = 1.8).

All of the participants completed a questionnaire designed to assess the amount of experience relevant to spatial visualization ability. The questionnaire began by describing spatial visualization abilities as those used in the production or interpretation of drawings in which three-dimensional objects were represented in two-dimensional form. The first item in the questionnaire requested participants to rate (on a 5-point scale) the importance of spatial visualization abilities in their current, or most recent, job. As expected, all of the architects assigned the highest rating of importance for spatial visualization abilities in their jobs. Only two of the unselected adults assigned a rating greater than 1.0, and the mean importance rating was 1.3 for this group compared with 5.0 for the architects.

The second item in the questionnaire asked respondents whether they had ever had a job in which spatial visualization abilities were important, and if so, to indicate how long they had held that job and how many years had elapsed since they had last worked in that job. All of the architects reported that they had worked in a job requiring spatial visualization abilities, with an average duration of 40.5 years. One of the architects had retired 2 years previously, and consequently the average number of years since last holding a relevant job was 0.2 years. Three of the unselected adults reported that they had once worked in a job requiring spatial visualization abilities. The average duration these individuals worked on that job was 14 years, with an average elapsed time since last holding that position of 26 years.

Finally, respondents were asked to estimate the number of hours per month they spent producing or interpreting drawings of three-dimensional objects in their work and in their hobbies or leisure activities (e.g., in designing or building furniture or scale models). The architects estimated that they devoted an average of 135 hr per month of their work time, and 32.4 hr per month of their leisure time, to the production or interpretation of drawings of three-dimensional objects. In contrast, the three unselected adults with relevant experience estimated that they spent only about 30 hr per month in the production or interpretation of drawings of three-dimensional objects when they were working in a job involving spatial visualization abilities. The average hours per month engaged in leisure activities involving spatial visualization abilities for all 10 of the unselected adults was 0.6.

Procedure. Because the psychometric tests and experimental tasks were identical in content and sequence to those described in Salthouse et al. (in press), only a brief summary of the procedures is provided here. In the first session, participants were administered the four paper-and-pencil tests of spatial visualization used in Study 1, along with the Wechsler Adult Intelligence Scale-Revised (WAIS-R; Wechsler, 1981) Block Design Test. Part 1 of each test was administered in the order: Paper Folding, Surface Development, Cube Comparisons, and Form Board, followed by the Block Design Test, and then Part 2 of each test in the reverse order of original presentation. The computer-controlled tasks were administered in subsequent sessions, with one or two tasks presented in each session.

Five of the computer-controlled tasks loosely resembled the paper-and-pencil spatial visualization tests. The paper-folding task (Session 2) consisted of successive displays of a rectangle being folded from one to four times, followed by a hole being punched through a folded surface. The participant was then asked to decide whether a displayed pattern of holes was consistent with the pattern that would have resulted from the preceding sequence of folds and punch location. A total of 240 separate trials were presented in this task. The cube-folding task (Session 3) involved the presentation of 288 trials, each containing six squares that could be assembled into a cube. Two of the squares contained outward-pointing arrows, and the participant was asked to decide whether the arrows would be facing one another when the squares were assembled into the cube. The spatial-integration task (Session 5) involved displays of one to four frames containing line-segment patterns; the participant was asked to integrate those segments into a unitary composite and to decide whether it matched a comparison pattern. A total of 280 trials were distributed across conditions varying in the number of to-be-integrated frames. Two versions of a cube-comparisons task (Session 4) were presented, one in which all faces of the two cubes were simultaneously visible, and the other in which only one face on either cube could be examined at any given time. In both versions of the task, the configurations had varied orientations relative to one another, and the participant was required to determine whether the two configurations could represent the same cube. The total number of cube comparisons trials across the two versions of the task was 144.

Two other tasks administered in the study were a block design task (Session 3) implemented on a computer (cf. Salthouse, 1987), and a spatial working-memory task (Session 2) involving the retention of line

Table 1
Summary Statistics of Performance Measures From Study 2

Measure	Unselected adults *M*	Unselected adults *SD*	Architects *M*	Architects *SD*
Psychometric test				
Paper Folding	−2.51	0.71	−1.24	1.05
Surface Development	−2.75	1.38	−1.40	1.39
Form Boards	−2.01	0.94	−0.84	1.29
Cube Comparison	−1.58	0.92	−1.18	0.99
Block Design	−1.89	1.07	−0.83	1.42
Computerized test				
Accuracy				
Paper Folding	−2.65	1.20	−0.75	1.42
Cube Folding	−1.98	1.32	−0.58	1.49
Spatial Integration	−1.24	0.98	−0.51	1.50
Cube Comparison				
Simultaneous	−1.72	1.46	−0.35	1.58
Successive	−1.89	1.72	−0.27	1.49
Time				
Paper Folding	1.38	1.49	3.23	2.29
Cube Folding	2.95	3.53	4.73	5.01
Spatial Integration	1.57	1.60	4.53	5.90
Cube Comparison				
Simultaneous	3.04	2.40	3.28	1.66
Successive	1.75	1.56	3.13	1.48

positions while using a mouse interfaced to the computer to connect points to produce irrelevant lines.

Results

Performance of the two groups in the psychometric tests is summarized in the top portion of Table 1. Notice that, as expected from the results of Study 1, the two groups are generally performing at about 1.0–2.0 *SD* units below the level of young adults. Of potentially greater interest than this age difference, however, is that the architects performed better than did the unselected adults in each of the tests. Analyses on a composite score, based on the average *z* score across the five tests, revealed that the architects ($M = -1.10$, $SD = 1.05$) performed significantly better than the unselected adults ($M = -2.15$, $SD = 0.79$), $t(18) = -2.54$, $p < 05$. Because there were 50 young adults in the standardization sample, statistical significance of the age differences in each group can be evaluated by means of *t* tests contrasting the values of each group against a mean of 0 and a standard deviation of 1. To illustrate, the *t* values for the composite scores were $t(58) = -3.05$, $p < .01$, for the contrast of older architects and young adults, and $t(58) = -7.52$, $p < .01$, for the young adult–unselected older adult contrast.

The initial data analyses in the computer-controlled tasks consisted of analyses of variance (ANOVAS) on the measures of percentage of correct decisions and median time per correct decision with group (unselected vs. architect) and level of experimental manipulation (e.g., number of folds in the paper-folding and cube-folding tasks, number of to-be-integrated frames in the spatial integration task, and number of 90° cube rotations in the cube-comparisons task) as factors. Only one of the Group × Manipulation interactions, that of Group × Number-of-90°-Cube-Rotations in the simultaneous version of the cube-comparisons task with the variable of decision accuracy, was significant, $F(5, 90) = 2.46$, $MS_e = 226.60$, $p < .05$. This interaction originated because the two groups were equivalent when the cube configurations were in the same orientation, but the architects were more accurate than the unselected adults when the configurations differed by more than 90°. Because, with this single exception, the differences between the two groups were approximately constant across levels of the experimental manipulations, in all subsequent analyses the data were collapsed across within-task conditions to yield single measures of time and of accuracy in each task.

Mean levels of accuracy for the two groups in five of the computer-controlled tasks are displayed in the middle rows of Table 1. Notice that although both groups were less accurate than the standardization group of young adults, the architects were more accurate than their unselected age peers in each task. The difference between the two older groups on the composite (average) measure of spatial visualization accuracy was significant (unselected $M = -1.90$, $SD = 1.07$, architects $M = -.49$, $SD = 1.17$), $t(18) = -2.80$, $p < .05$. Only the unselected group performed significantly lower than young adults; unselected, $t(58) = -5.18$, $p < .01$; architects, $t(58) = -1.24$, $p > .05$.

Means of the two groups for the median time to reach correct decisions in these same tasks are displayed in the bottom rows of Table 1. That all of the values are above the average of young adults indicates that both groups of older adults were slower in their decisions than were the young adults. It is interesting, however, that the architects were generally slower in their decisions than the unselected adults. This pattern was evident in the measures from each task, but the group difference was not significant in a *t* test on the composite (average) measure of spatial visualization time (unselected $M = 1.95$, $SD = 1.71$; architects $M = 3.57$, $SD = 2.44$), $t(18) = -1.83$, $p > .10$. Both groups of older adults took significantly more time than young adults to reach their decisions, unselected, $t(58) = 3.08$, $p < .01$; architects, $t(58) = 4.55$, $p < .01$.

Participants in the paper-folding and spatial-integration tasks controlled the time they spent studying the displays preceding the comparison stimulus, and consequently it was possible to analyze the average inspection durations in each of these tasks. The architects studied both sets of displays longer than the unselected adults, but in neither case was the difference statistically significant (i.e., $p > .05$). The study durations in the paper-folding task averaged 1.46 ($SD = 2.13$) young standard deviation units for the unselected adults, and 5.21 ($SD = 6.22$) young standard deviation units for the architects, $t(18) = 1.80$. Study durations in the spatial-integration task averaged 1.60 ($SD = 1.30$) young standard deviation units for the unselected adults, and 2.64 ($SD = 2.69$) for the architects, $t(18) = 1.11$.

The primary variable of interest in the computer-controlled block design task was the average number of block manipulations required to reproduce the stimulus matrix (see Salthouse, 1987, for details). Means of this measure were 1.85 ($SD = 1.46$) young standard deviation units for the unselected adults and 0.76 ($SD = 2.78$) young standard deviation units for the architects, $t(18) = 1.10$, $p > .05$. Efficiency of the block manipulations was also examined as a function of the relation between the target pattern and the initial displayed configuration of the block. A Group (architect vs. unselected) × Relation (which block face matched the target pattern) ANOVA revealed that neither the group main effect nor the Group × Relation interaction was significant ($p > .05$).

No group differences were evident in either the first or the second administration of the spatial-memory task, but in both cases performance was lower than that of the standardization group of young adults. Performance measures from several participants were unavailable because of computer malfunction, but means for the first administration of the 7 unselected adults and the 8 architects with analyzable data were −0.87 (SD = 1.24) and −1.05 (SD = 0.66) standard deviation units, respectively, $t(13) = 0.35$. Values for the 8 unselected adults and 9 architects with analyzable data for the second administration were −1.23 (SD = 0.87) and −0.69 (SD = 0.93), respectively, $t(15) = 1.23$.

Discussion

The results of both Studies 1 and 2 indicate that increased age is associated with lower levels of performance in tests of spatial visualization ability. On the average, across performance measures and subject groups, adults in their 60s appear to perform about 1.0–2.0 *SD*s below the mean level of 20-year-olds. However, the results of Study 2 suggest that these age differences may be less pronounced among individuals whose occupation provides them with extensive amounts of experience using spatial visualization abilities. Although not always statistically significant because of the low statistical power associated with the small sample sizes, the architects were more accurate than the unselected adults in every available comparison of spatial visualization performance.

Examination of the inspection and decision times revealed that the architects generally spent a longer time studying the stimuli and making their decisions than the unselected adults. It is therefore conceivable that the higher levels of accuracy achieved by the architects were a consequence of their devoting more time to all phases of the tasks than the unselected adults. On the other hand, it is also possible that the architects could have been able to perform more accurately than the unselected adults even had the two groups spent the same amount of time in each phase of the tasks. Unfortunately, it appears impossible to distinguish among these alternatives with the available data.

Study 3

Perhaps the most interesting result of Study 2 is the consistent superiority of the architects over the unselected adults in the accuracy of performance in spatial visualization tasks. This finding is subject to two quite different interpretations.

One view, which might be termed *differential preservation*, attributes the group differences to the extensive amount of experience with spatial visualization activities on the part of the architects. That is, according to this perspective, the architects performed better than the unselected adults because their 40 years of experience using spatial visualization abilities in their architectural profession contributed to the maintenance or preservation of abilities that would have declined in the absence of this experience.

The second interpretation of the architect/unselected difference in Study 2, which can be designated the *preserved differentiation* view, postulates that the differences between the two groups in their 60s are merely continuations of differences that existed when the individuals were young adults. In other words, this view suggests that initial differences in spatial visualization ability, which may have originally contributed to the choice of one's profession, were simply preserved as the people grew older.

One means of attempting to distinguish between these two interpretations consists of examining the relation between age and spatial visualization performance in a sample of architects who have been continuously using their spatial visualization abilities. If the differential preservation interpretation is correct, then little or no effects of age should be evident among people for whom age and amount of relevant experience are highly correlated. On the other hand, age-related effects comparable with those observed among unselected adults might be expected from the preserved differentiation interpretation because effects related to age could be independent of the factors contributing to the individual differences in spatial visualization ability evident in young adulthood.

The current study used this research strategy by obtaining three measures of spatial visualization performance from practicing architects whose ages ranged between 21 and 71 years. One of the spatial visualization measures was the score on the paper-and-pencil Surface Development Test, and the other two were derived from slightly modified versions of the computer-controlled paper folding and spatial integration tasks used in Study 2.

Method

Subjects. Research participants consisted of 47 male architects between 21 and 71 years of age (M = 45.0 years, SD = 13.9). The mean years of education was 17.8 (age correlation = .00), and self-assessed health status on the 5-point rating scale described earlier was 1.3 (age correlation = −.18).

Means, and correlations with age, of the responses to the items on the experience questionnaire described in Study 2 were as follows: self-rated importance of spatial visualization abilities in current job, M = 4.9, age correlation = −.34; years in relevant job, M = 20.8, age correlation = .97; hours per month producing or interpreting drawings of three-dimensional objects during work, M = 101.2, age correlation = −.50; and hours per month producing or interpreting drawings of three-dimensional objects in one's hobbies or leisure activities, M = 10.9 hr, age correlation = −.32. All these age-experience correlations were significant at $p < .05$.

Procedure. The three tasks performed by each participant were Part 1 of the Surface Development Test (Ekstrom et al., 1976) and computer-controlled paper-folding and spatial-integration tasks. All of the participants received the tasks in this same order. The paper-folding task consisted of a repeatable set of 4 practice trials, followed by two blocks of 56 trials each. Within each trial block, 8 of the trials had one fold prior to the hole punch, 16 had two folds, and 24 had three folds. An additional 8 trials in each block had no folds and, instead, merely involved recognition judgments about the identity of two patterns of circles. The purpose of these trials was to monitor the participants' attention to the task and their ability to remember configurations representing patterns of punched holes. The time spent inspecting the consequences of each fold was under the control of the participant, as was the time to reach a decision about the comparison stimulus.

The spatial-integration task consisted of a repeatable set of 8 practice trials followed by two blocks of 50 trials each. Across the two blocks, 25 trials each were presented with one, two, three, or four frames prior to the comparison stimulus. The comparison stimulus always contained 12 line segments, and hence the number of segments per frame was 12 for one-frame trials, 6 for two-frame trials, 4 for three-frame trials, and 3 for four-frame trials. As in the paper-folding task, both the time spent inspecting each frame and the time to reach a decision about the comparison stimulus were under the control of the participant.

Results and Discussion

Figure 3 displays performance on the Surface Development Test of individual architects as a function of their age. It is obvious that there is a strong negative relation between age and Surface Development score among the individuals in this sample. The regression equation for these data, represented by the solid line, revealed that there was a decrease of about 3.2 items with each additional 10 years of age. For purposes of comparison, the regression line relating age to score on Part 1 of the Surface Development Test for the 50 unselected adults of Study 1 is also displayed as a dotted line in Figure 3. It can be seen that, if anything, the age relation is less pronounced among the individuals in the sample who presumably have relatively little experience using spatial visualization abilities. The correlation with age in the unselected sample was −.39 compared with the −.69 in the sample of architects ($z = 1.43, p > .05$), and the regression slope was −1.9 items per decade compared with the −3.2 for the sample of architects.

Because the Surface Development Test has time limits that prevent many participants from attempting all items, it is possible that the age-related effects in this test are at least partially attributable to slower perceptual–motor processes rather than to an actual decrease with age in spatial visualization ability. This possibility can be investigated by examining performance

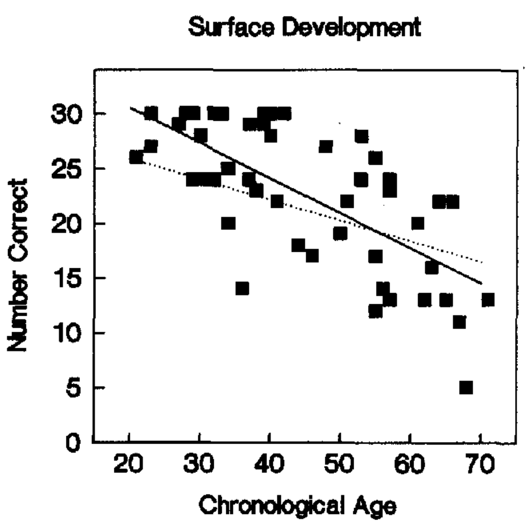

Figure 3. Scatterplot of number of items answered correctly in the Surface Development Test as a function of age in Study 3. (The solid line represents the regression equation for the displayed data, and the dotted line represents the regression equation for the relevant data of the 50 unselected adults of Study 1.

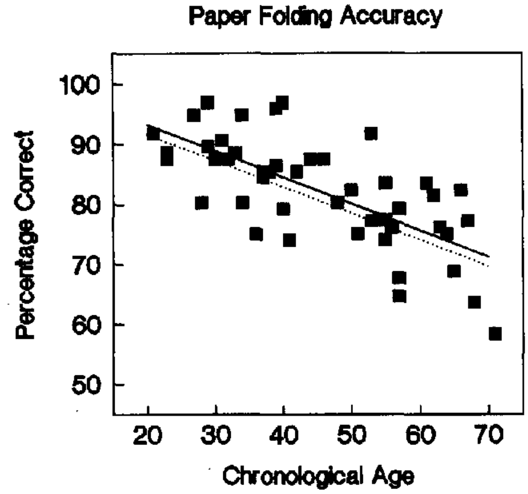

Figure 4. Scatterplot of accuracy in the computer-controlled paper-folding task as a function of age in Study 3. (The solid line represents the regression equation for the displayed data and the dotted line represents the regression equation for the data of 120 adults in a study by Salthouse, Mitchell, Skovronek, & Babcock, 1989.)

in the computer-controlled tasks, in which separate time and accuracy scores were available because the items were individually presented.

Accuracy of the paper-folding decisions averaged across one, two, and three folds is illustrated in Figure 4 as a function of the age of the architects. (Accuracy with zero folds is not included because very few errors were made in this control condition and the correlation with age was −.01.) The solid line represents the regression equation for the data of the architects, and the dotted line indicates the regression equation for comparable trials in the sample of 120 adults tested in Salthouse, Mitchell, Skovronek, and Babcock (1989). These individuals ranged from 20 to 79 years of age, 20 in each decade, and were similar to those in Study 1 in that they were all male graduates of a university with a primarily technically oriented curriculum. Age trends were very similar in the two samples, with a correlation of −.71 ($p < .01$) for the architects and −.52 ($p < .01$) for the unselected adults ($z = 1.06, p > .1$), and identical regression slopes of −4.4% per decade. Both samples also exhibited comparable relations between age and decision time (i.e., age correlations of .61 for architects and .41 for unselected adults) and between age and median inspection time of displays prior to the comparison stimulus (i.e., age correlations of .28 for architects and .37 for unselected adults).

Decision accuracy of individual architects in the spatial-integration task as a function of their age is displayed in Figure 5. The age correlation of −.47 ($p < .01$), and the regression slope of −2.9% per decade, indicate that, as with the other measures of spatial visualization performance, increased age in this sample was associated with generally lower levels of accuracy.

Analyses of median decision time and median time studying each frame containing line segments to be integrated into the composite pattern revealed that neither variable was significantly ($p < .05$) related to age. The age correlations were .15 for the decision time measure and −.09 for the study time measure.

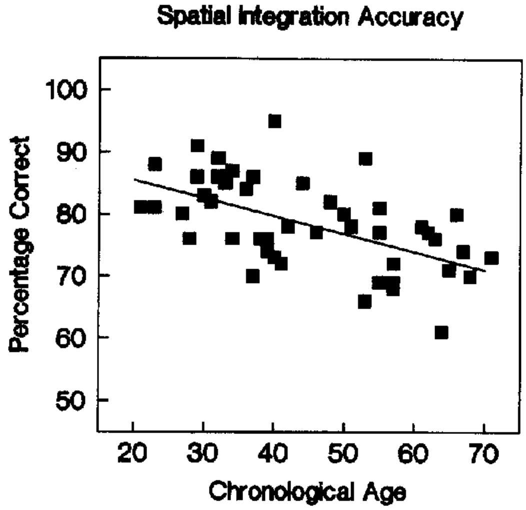

Figure 5. Scatterplot of accuracy in the computer-controlled spatial integration task as a function of age in Study 3. (The solid line represents the regression equation for the displayed data.)

It may be remembered that statistically significant negative age correlations were found with the variables of reported importance of spatial visualization abilities in one's current job and estimated number of hours per month in work or leisure activities using spatial visualization abilities. One possible interpretation of these correlations is that with increased age there is a shift in the pattern of activities within the same occupation, so that as the architects become older they spend less time actually using their spatial visualization abilities and that it is this lack of recent exercise that is responsible for the observed age-related declines in spatial visualization performance.

Although clearly plausible, two points should be considered in evaluating this interpretation. The first is that the correlation of −.34 between age and rated importance of spatial visualization abilities in one's current job is completely attributable to three individuals, because all of the other 44 participants assigned the maximum rating of 5. One of these individuals, age 68 years, assigned a rating of 3, and the other two, ages 53 and 67 years, assigned importance ratings of 4.

The second point is that although the −.50 correlation between age and estimated number of work hours per month using spatial visualization abilities is impressive, note that even the oldest participants reported spending considerable time producing or interpreting drawings of three-dimensional objects. To illustrate, architects from 21 to 45 years of age estimated that they spent about 123 hr per month using spatial visualization abilities in their work, but architects ages 46 to 71 years estimated that their time investment was still about 76 hr per month. Even this latter value represents a substantial amount of relevant experience compared with most members of the general population.

Despite these reservations, it is nevertheless important to examine the possibility that the age trends in the measures of spatial visualization ability observed in the current study might have been attributable to age-related shifts in the pattern of occupational and leisure activities. This was accomplished by examining the effects of age on spatial visualization performance in multiple-regression analyses after first controlling for the variables of rated importance of spatial visualization in one's current job, and the estimated number of work hours and leisure hours using spatial visualization abilities.

The outcome of these analyses was identical for each of the dependent measures. In each case, the age effects remained significant ($p < .01$) after statistical control of the other variables, and the regression coefficients estimating the relation between age and performance were very similar to those obtained when age was the only predictor variable. That is, the age slopes were −3.2 items per decade in both analyses of the score in the Surface Development Test, −4.4% per decade for the initial regression and −5.7% per decade for the adjusted regression of paper-folding accuracy, and −2.9% per decade for the initial regression and −3.5% per decade for the adjusted regression of spatial integration accuracy. The unambiguous conclusion from these analyses, therefore, is that the observed age trends in spatial visualization performance are not explainable in terms of age-related shifts in the type or extent of experience using spatial visualization abilities among practicing architects.

General Discussion

Several studies have previously been reported involving comparisons of adults of different ages from the same occupation, but there have been very few attempts to match tasks to specific occupations in order to investigate age-related effects among highly experienced individuals. For example, although there have been a few studies comparing school teachers in various aspects of memory performance (Fraser, 1958; Klein & Shaffer, 1986; Lachman, Lachman, & Taylor, 1982; Moenster, 1972), or in measures of reasoning (Garfield & Blek, 1952) or creativity (Alpaugh & Birren, 1977), it is not obvious why members of this occupation should be expected to differ from the general population in type or amount of experience using these abilities.

An explicit goal of Studies 2 and 3 in the current project was to investigate age-related effects in spatial visualization ability among members of an occupation in which these abilities are in virtually constant use. The field of architecture was selected as the target occupation, initially because of the intuition that spatial visualization ability was probably important in the daily activities of architects. This intuition was substantiated in the reports of the architects participating in the project because only 3 of the 57 architects in Studies 2 and 3 assigned less than the maximum rating in evaluating the importance of spatial visualization abilities in their job. These individuals also estimated that they devoted an average of over 100 hr per month to the production or interpretation of drawings of three-dimensional objects requiring spatial visualization abilities. This experience is even more impressive when it is realized that it is cumulative in that the number of years working as an architect was almost perfectly correlated (i.e., $r = .97$) with age. Increased age in these individuals was therefore associated with an enormous accumulation of relevant experience.

Of course, it is possible that the measures of spatial visualization ability investigated in the current studies were unrelated to the type of spatial visualization actually used by architects.

Although we cannot completely rule out this possibility, two sets of observations seem to argue against the proposal that different types of spatial visualization were involved in our assessments and in the normal activities of architects. The first set of results are those of Study 2 indicating that the architects were generally more accurate than their unselected age peers on all the available measures of spatial visualization ability. Evidence of this type is usually interpreted as demonstrating the validity of the measures for assessing abilities required in the target occupation, and thus it seems unlikely that the current measures are totally unrelated to the activities performed by practicing architects.

A second set of observations relevant to evaluating the possibility that architects rely on a different type of spatial visualization ability than that assessed in these studies derives from informal questioning of several research participants after they had completed their participation in the project. Without exception, these individuals reported that the psychometric tests and experimental tasks they performed seemed to involve processes similar to those used in producing or interpreting drawings of three-dimensional objects. The assessment procedures were sometimes characterized as rather abstract, but most respondents agreed that processes such as the mental assembly of discrete pieces of spatial information, and imagining transformations of rigid spatial configurations, were frequently required in the activities they performed as architects.

Another factor to consider when interpreting the present results is the possibility that the selection criteria for admission into architectural degree programs might have changed over time, so that greater emphasis was placed on abstract spatial visualization skills for more recent, and hence younger, architects. To the extent that selection criteria have changed in this manner, at least some of the age trends observed in Figures 3, 4, and 5 might be attributed to systematic shifts in sample selection rather than to any intrinsic aging-related processes. The primary difficulty with this interpretation is that it fails to explain why nearly identical age trends were observed among unselected adults for whom potential shifts in criteria used to guide admission into architectural programs were apparently not operative.

If it is accepted that the present sample of architects had considerable experience using relevant spatial visualization abilities, then the results of the current studies seem to imply that increased age is associated with lower levels of spatial visualization ability even among individuals who are using these abilities extensively in their occupation. A similar finding of relatively little influence of experience on the age trends in the efficiency of specific processes was reported by Salthouse (1984) and Salthouse and Saults (1987). Experience in these studies was assessed in terms of various indexes of the time engaged in transcription typing, and the measures of relevant performance consisted of choice reaction-time and visual–manual transcription or substitution rate. Although relative to the young individuals, the older individuals in these studies had considerably more cumulative typing experience, and hence presumably more experience with the components of rapid responding and visual–motor substitution, the age-related trends for the measures of reaction time and substitution rate in these studies were nearly identical to those reported in studies involving unselected samples of adults.

The discovery of sizable age-related effects on performance measures relevant to frequently performed occupational activities among architects in the present study, and among typists in the earlier studies, suggests that the influence of age-related factors on certain aspects of cognitive functioning may be relatively independent of experience. These findings therefore appear inconsistent with interpretations postulating that a major determinant of age-related differences in cognition is a lack of recent exercise or practice with the relevant abilities on the part of older adults. Experience clearly contributes to greater proficiency in many aspects of performance, but the results of these studies seem to suggest that it apparently does not substantially alter the effects associated with increased age on measures of some of those aspects.

It is important to emphasize that even though the present results suggest that older architects are less proficient than their younger colleagues in several measures of spatial visualization ability, it should not be concluded that there is a negative relation between age and professional competence as an architect. It is quite possible that a different level of analysis, or a focus on other architectural activities, would reveal benefits associated with increased experience and age. Architectural competence obviously involves much more than the efficiency of executing certain types of spatial transformations, and none of these other aspects, which might be expected to increase with experience, were evaluated in these studies. For example, amount of relevant knowledge about the interrelations of building materials, building type, and building site almost certainly accumulate with experience, and yet no assessment of this kind of knowledge was attempted in these studies. A reasonable goal for future research is to attempt to identify how specific abilities and various forms of knowledge combine to produce high levels of competence in the architectural (or any other) profession and to determine whether there are changes in this mixture with increased age or experience.

References

Alpaugh, P. K., & Birren, J. E. (1977). Variables affecting creative contributions across the adult life span. *Human Development, 20,* 240–248.

Ekstrom, R. B., French, J. W., Harman, H. H., & Dermen, D. (1976). *Manual for kit of factor-referenced cognitive tests.* Princeton, NJ: Educational Testing Service.

Fraser, D. C. (1958). Decay of immediate memory with age. *Nature, 182,* 163.

Garfield, S. L., & Blek, L. (1952). Age, vocabulary level, and mental impairment. *Journal of Consulting Psychology, 16,* 395–398.

Kirasic, K. C., & Allen, G. L. (1985). Aging, spatial performance, and spatial competence. In N. Charness (Ed.), *Aging and human performance* (pp. 191–223). Chichester, England: Wiley.

Klein, H. A., & Shaffer, K. (1986). Aging and memory in skilled language performance. *Journal of Genetic Psychology, 146,* 389–397.

Lachman, R., Lachman, J. L., & Taylor, D. W. (1982). Reallocation of mental resources over the productive lifespan: Assumptions and task analyses. In F. I. M. Craik & S. Trehub (Eds.), *Aging and cognitive processes* (pp. 279–308). New York: Plenum Press.

Lohman, D. F. (1988). Spatial abilities as traits, processes, and knowledge. In R. J. Sternberg (Ed.), *Advances in the psychology of human intelligence* (Vol. 4., pp. 181-248). Hillsdale, NJ: Erlbaum.

Lohman, D. F., Pellegrino, J. W., Alderton, D. L., & Regian, J. W. (1987). Dimensions and components of individual differences in spatial abilities. In S. H. Irvine & S. E. Newstead (Eds.), *Intelligence and cognition: Contemporary frames of reference* (pp. 253-312). Dordrecht, The Netherlands: Martinus Nijhoff.

McGee, M. G. (1979). Human spatial abilities: Environmental, genetic, hormonal, and neurological influences. *Psychological Bulletin, 86,* 889-918.

Moenster, P. A. (1972). Learning and memory in relation to age. *Journal of Gerontology, 27,* 361-363.

Ratner, H. H., Schell, D. A., Crimmins, A., Mittelman, D., & Baldinelli, L. (1987). Changes in adults' prose recall: Aging or cognitive demands? *Developmental Psychology, 23,* 521-525.

Salthouse, T. A. (1984). Effects of age and skill in typing. *Journal of Experimental Psychology: General, 113,* 345-371.

Salthouse, T. A. (1987). Sources of age-related individual differences in block design tasks. *Intelligence, 11,* 245-262.

Salthouse, T. A., Babcock, R. L., Mitchell, D. R. D., Palmon, R., & Skovronek, E. (in press). Sources of individual differences in spatial visualization ability. *Intelligence.*

Salthouse, T. A., Mitchell, D. R. D., Skovronek, E., & Babcock, R. L. (1989). Effects of adult age and working memory on reasoning and spatial abilities. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 15,* 507-516.

Salthouse, T. A., & Saults, J. S. (1987). Multiple spans in transcription typing. *Journal of Applied Psychology, 22,* 187-196.

Smith, I. M. (1964). *Spatial ability: Its educational and social significance.* London: University of London Press.

Sorenson, H. (1933). Mental ability over a wide range of ages. *Journal of Applied Psychology, 17,* 729-741.

Sorenson, H. (1938). *Adult abilities.* Minneapolis: University of Minnesota Press.

Thorndike, E. L., Bregman, E. O., Tilton, J. W., & Woodyard, E. (1928). *Adult learning.* New York: Macmillan.

Wechsler, D. (1981). *WAIS-R manual.* New York: Psychological Corporation.

Willis, S. L. (1987). Cognitive training and everyday competence. In K. W. Schaie (Ed.), *Annual review of gerontology and geriatrics* (Vol. 7., pp. 159-188). New York: Springer.

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