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Effects of Age and Naturally Occurring Experience on Spatial Visualization Performance

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A questionnaire designed to assess experience with activities presumed to require spatial visualization abilities, and psychometric tests of these abilities, were administered to 383 adults ranging from 20 to 83 years of age. Although research participants varied considerably in the amount of self-reported experience, statistical control of experience resulted in relatively modest attenuations of the relations between age and spatial visualization performance. These findings seem inconsistent with a strong disuse interpretation of cognitive aging phenomena and suggest that at least some age-related differences in cognitive functioning are independent of the amount of experience with relevant activities.

One of the most popular hypotheses proposed to account for the age-related declines observed with certain measures of cognitive functioning attributes those declines to various forms of disuse or lack of practice. Although seldom articulated as an explicit theory, the following sample of quotations illustrates that this perspective has been implicitly accepted for more than half a century.

> A decrease in test ability among adults is probably caused by the fact that adults, as they grow older, exercise their minds less and less with the materials found in psychological tests. (Sorenson, 1933, p. 736)

> The "losses" are in large measure . . . a by-product of disuse . . . old age acts selectively and most decidedly on those functions which have suffered for want of practice. (Sward, 1945, pp. 478–479)

> [I]n one's own field where experience has been accumulating over a period of many years, there is little evidence for any decline with the years, at least until extreme old age is reached. (Gilbert, 1952, p. 130)

> Those who have spent their lives working with their hands and interpreting perceptual data retain the ability to deal with perceptual and constructional problems. (Williams, 1960, pp. 217–218)

> [S]tudies of the functions of the organism within his own environment show relatively small age-related differences or changes and in many cases advancing age is correlated with improvement. (Fozard & Thomas, 1975, p. 117)

> [T]he declines that are observed in abilities which are used frequently appear to begin at a later age and to be less drastic than are the declines in abilities which are exercised less frequently. (Denney, 1982, p. 824)

> Ability tasks that are commonly used in everyday life tend to be insensitive to age. (Birren, Cunningham, & Yamamoto, 1983, p. 552)

> [W]hen tasks relate more strongly to the ecological niches that the older person inhabits, age-related deficits are less prominent. (Charness, 1985, p. 226)

An important category of research relevant to the disuse hypothesis has involved comparisons across people presumed to differ in the nature and extent of their experiences. Research within this category has varied with respect to whether the focus on the individual's experience and cognitive performance has been broad or narrow. Studies with a broad focus have attempted to relate characterizations of the individual's general activity level (e.g., Arbuckle, Gold, & Andres, 1986; DeCarlo, 1974; Schooler, 1984) or his or her self-assessed cognitive demands (e.g., Owens, 1953; Schwartzman, Gold, Andres, Arbuckle, & Chaikelson, 1987) either to a variety of miscellaneous cognitive measures or to a composite score of general intelligence. Most of these studies have reported rather weak relations between experience and cognitive functioning. For example, the semipartial correlation between a measure of the frequency of 23 activities and a composite measure of intelligence in the Schwartzman et al. (1987) study was only .13.

Although not without value, studies with a broad focus suffer from two problems associated with the grossness of the categorization of both the experience and the cognition constructs. One problem is that it is difficult to rule out the influence of potentially confounding third variables (such as health status) when the evaluations neither of experience nor of cognition are very specific. A second problem is that the relations between experience and cognition are likely to be quite weak when those constructs are assessed in very general terms. That is, the greatest effects of experience will probably be evident between specific measures of cognition and particular frequently performed activities, rather than between global measures of cognition or general intelligence and gross categorizations of experience.

One means of achieving closer linkages between experience and cognition is to rely on samples comprising members of

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particular occupational groups and to investigate age-related effects on occupationally relevant measures of cognitive performance. Perhaps the earliest, and almost certainly the largest, of the occupation-specific studies relevant to aging involved a battery of perceptual and cognitive tests administered to 544 aircrew officers (Glanzer & Glaser, 1959; Glanzer, Glaser, & Richlin, 1958). The stated purposes of this project were to "measure the skills required for performance of aircrew officers [and to] measure the effects of aging upon skilled performance" (Glanzer & Glaser, 1959, p. 89). Unfortunately, the assessment of age-related effects was not very powerful because of a relatively narrow range of ages, with only 14, or less than 3%, of the research participants over the age of 40. Despite this restricted age range, significant negative correlations between age and performance were reported on 8 of the 14 tests. Furthermore, the largest age effects were evident on a test with the highest face validity as a measure of pilot skill. This was a test titled Instrument Comprehension, in which the examinee is required to integrate information from a compass and an artificial horizon to indicate the current position of an airplane. Not only was the simple age correlation with this measure statistically significant ($r = -.33$), but it was only slightly attenuated (to $r = -.24$) after statistically controlling the presumably relevant variable of total number of hours of flying experience.

A similar finding of significant age-related cognitive differences favoring younger adults within a sample of adults for whom the relevant abilities can be assumed to have been in continuous use was recently reported by Salthouse, Babcock, Skovronek, Mitchell, and Palmon (1990). Most of the participants in this project were architects, and the measures of cognitive performance consisted of scores on tests of spatial visualization. The 47 architects in Study 3 of that report ranged from 21 to 71 years of age, with a correlation of .97 between age and number of years of using spatial visualization abilities in one's job. Although it seems reasonable to assume that all of these practicing architects had extensive, and nearly continuous, use of spatial visualization abilities, highly significant age-related declines (i.e., age correlations of −.69, −.71, and −.47) were observed in three measures of spatial visualization performance.

The results of the two occupation-specific projects just described are therefore consistent in providing rather discouraging evidence for the disuse perspective of cognitive aging. Objections can be raised against each of these studies, however, and it is thus desirable to replicate the major results before reaching a definitive conclusion regarding the disuse interpretation. Unfortunately, the strategy of examining age trends in samples comprising members of a particular profession or occupation is hampered by the difficulty of recruiting appropriate research participants. To illustrate, in our recent study of architects, more than 1,100 letters were mailed to nearly all of the members of the American Institute of Architects professional organization residing in a large metropolitan area, and approximately 400 of these individuals were later telephoned to make additional appeals for participation. Ultimately, however, only about 60 individuals were successfully recruited to participate in the two relevant studies. Furthermore, it was impossible to determine whether the architects who participated in the project were representative of the larger population of architects.

A different research strategy was used in our present project by recruiting participants from the general population and then administering a questionnaire to evaluate the extent of each individual's experience with different activities presumed to require spatial visualization ability. Three types of information were requested in the questionnaire to assess recent experience, cumulative experience, and subjective ability. The two categories of experience were distinguished to allow investigation of age relations with both the current frequency and the accumulated frequency of activities presumed to be relevant to spatial visualization. Information about both kinds of experience is desirable because, although proponents of the disuse perspective generally argue that increased age is associated with lesser amounts of recent experience with relevant activities, the cumulative experience of an individual may actually be greater with increased age. Ratings of subjective ability were included because people who spend considerable time performing a given activity might be assumed to have higher perceptions of their level of ability in that activity than people who devote relatively little time to the activity. In this respect the subjective ability ratings may prove useful in evaluating the validity of the experience information.

In addition to the experience questionnaire, six cognitive tests were also administered to all research participants: two designed to assess spatial visualization ability, two designed to assess the closely related cognitive ability of inductive reasoning, and two designed to assess the presumably unrelated cognitive ability of perceptual speed. The purpose of the tests of inductive reasoning and perceptual speed was to provide a further check on the validity of the information obtained from the experience questionnaire. That is, if responses to the experience questionnaire are accurate indications of the amount of experience each individual has had with explicitly spatial activities, then a gradation in the magnitude of the correlations between the questionnaire responses and the measures of cognitive performance would be expected, with the highest correlations for the spatial visualization measures, lower correlations for the inductive reasoning measures, and the lowest correlations for the perceptual speed measures.

The primary questions investigated in the project were whether experience with activities requiring spatial visualization ability either mediates or moderates age-related differences in measures of spatial visualization performance. The mediation position would be supported if there is little or no effect associated with age after statistically controlling the influence of variables reflecting amount of relevant experience. A somewhat weaker hypothesis is that differential experience does not mediate the effects related to age but instead moderates those effects such that the age-related influences are smallest among individuals with the greatest amount of experience. The specific prediction from the moderation perspective, therefore, is that the age and experience variables will have interactive effects on measures of spatial visualization performance.

Method

Subjects

A total of 383 adults between 20 and 83 years of age contributed valid data to the project. The data from 5 additional individuals were considered invalid and were discarded prior to analyses because these participants had difficulty understanding the test materials or because they arrived at the testing session in an obviously inebriated state. All participants were recruited from newspaper advertisements and were tested in small groups. Participants consisted of 186 men and 197 women, with 20–47 individuals in each decade–sex grouping from the 20s to 70+. Each individual was paid $10 for his or her participation in the 90-min session.

Procedure

The testing session began with the research participants completing a questionnaire intended to assess the amount of recent and cumulative experience the individual had with activities presumed to require spatial visualization abilities and to obtain a self-appraisal of his or her level of ability in each activity. For each of 10 activities (listed in Table 2), the individual was asked to (a) rate his or her ability on a 5-point scale ranging from 1 (*much above average*) to 5 (*much below average*), (b) estimate the average number of hours per month devoted to that activity over the last 6 months, and (c) estimate the number of years in which an average of at least 15 hr per month had been devoted to that activity.

The remainder of the test session was devoted to the performance of six cognitive tests. The tests, in the order in which they were presented, were the Number Comparison Test, the Paper Folding Test, the Letter Sets Test, the Abstraction Test, the Surface Development Test, and the Finding As Test. All but the Abstraction Test were from the *Kit of Factor-Referenced Cognitive Tests* (Ekstrom, French, Harman, & Dermen, 1976). The Abstraction Test was from the Shipley Institute of Living Scale (Shipley, 1986).

The Paper Folding and Surface Development tests were intended to assess spatial visualization ability. The task in the Paper Folding Test is to determine which pattern of holes would result if a piece of paper were folded in the manner illustrated and a hole punched in the specified location. The individual is allowed 3 min to complete as many of the 10 five-alternative multiple-choice items as possible. Items in the Surface Development Test consist of an unfolded and an assembled drawing of a three-dimensional object, for which the examinee is required to determine the correspondence between edges in the two drawings. Individuals are allowed 6 min to complete as many of the 30 items as possible.

The Letter Sets and Abstraction tests were designed to assess inductive reasoning ability. The task in the Letter Sets Test is to determine which of five sets of letters is different in some way from the remaining sets of letters. The examinee is allowed 7 min to perform the 15 problems in the test. The Abstraction Test is a series completion test containing sequences of numbers, letters, or words that are to be completed by supplying the item that most naturally continues the sequence. The individual is permitted 5 min to solve the 20 items on the test.

The Number Comparison and Finding As tests were designed to assess perceptual speed. The task in the Number Comparison Test is to decide as rapidly as possible whether two numbers are the same or different. A time limit of 90 s is provided for examinees to complete as many of the 48 items as possible. The task in the Finding As Test is to locate all of the words containing the letter "a" in five columns of 41 words each. The examinee is allowed 2 min to detect as many of the 100 targets as possible.

Results

Cognitive Performance Measures

For most of the analyses, performance in each test was summarized by the number of items answered correctly minus the number of items answered incorrectly. This scoring method has the dual advantage of providing a correction for guessing while also increasing the range of possible scores. The correlation matrix illustrating the relations among these cognitive performance measures and the variables of age, sex, education, and self-reported health status is displayed in Table 1.

Because the cognitive tests were selected a priori to represent three distinct abilities, and because the largest correlation with each measure was generally with the other measure hypothesized to represent the same ability (Table 1), composite ability scores were created by averaging the z scores from the two relevant measures. That is, a spatial visualization composite was created by averaging the individual's z scores from the Paper Folding and Surface Development tests, an inductive reasoning composite was created by averaging z scores from the Letter Sets and Abstraction tests, and a perceptual speed composite was created by averaging z scores from the Number Comparison and Finding As tests. Correlations of these composite measures with chronological age were −.37 for spatial visualization, −.27 for inductive reasoning, and −.28 for perceptual speed (all significant at $p < .01$). Although conceptually distinct, the composite measures were not independent, because the intercorrelations were .69 between spatial visualization and inductive reasoning, .33 between spatial visualization and perceptual speed, and .51 between inductive reasoning and perceptual speed.

Questionnaire Responses

Means and standard deviations of the responses to the individual questionnaire items are presented in Table 2. Responses were missing on one or more items in 40 of the questionnaires; hence, all subsequent analyses are based on data from the 343 individuals with complete records. In all cases, higher numbers reflect greater quantities, with the values in the recent experience column representing hours per month over the last 6 months and those in the cumulative experience column representing years, with an average of at least 15 hr per month. Most of the distributions of recent experience responses were positively skewed. To illustrate, all of the medians (50th percentile values) were 3 or less, whereas the values at the 95th percentile for Items 1 through 10 were 37.5, 30, 30, 20, 20, 20, 40, 5, 10, and 4 hr per month, respectively. For all except the last three activities, therefore, a considerable amount of recent experience was reported by at least some of the research participants.

To reduce the number of questionnaire variables for subsequent analyses, a principal-components analysis was conducted on the data from all 30 items in the questionnaire. (Very similar results were obtained with oblique-rotation factor-analysis procedures; hence, the structural configuration of scores is not specific to this particular method of analysis.) Loadings of the items in excess of .3 on the eight components with eigenvalues greater than 1, after orthogonal rotation, are displayed in Table 3. Correlations between the component scores and the age, sex, spatial visualization, inductive reasoning, and perceptual speed variables are displayed in Table 4. None of the correlations between the component scores and the education or self-reported health variables was significant (i.e., $p > .05$); thus, they are not reported in Table 4.

The first three components can be interpreted as representing relatively broad or nonspecific cumulative experience, sub-

Table 1
Correlation Matrix for Performance Measures and Demographic Variables (N = 383)

Measure	1	2	3	4	5	6	7	8	9	10	*M*	*SD*
1. Age (years)	—	.13	−.01	.10	−.38*	−.30*	−.25*	−.26*	−.17*	−.30*	45.99	16.80
2. Sex[a]		—	−.05	.06	−.14*	−.22*	−.07	.01	.13	.17*	.51	.50
3. Formal education (years)			—	−.01	.26*	.23*	.30*	.27*	.14*	.13	15.14	2.52
4. Self-reported health[b]				—	−.02	−.06	.00	−.05	.00	−.08	1.99	1.09
5. Paper Folding					—	.67*	.60*	.59*	.21*	.29*	1.69	4.30
6. Surface Development						—	.58*	.54*	.24*	.30*	7.23	11.43
7. Abstraction							—	.69*	.33*	.36*	11.10	5.37
8. Letter Sets								—	.44*	.47*	7.52	4.79
9. Finding As									—	.46*	27.33	10.33
10. Number Comparison										—	22.20	6.16

[a] Male = 0, female = 1. [b] 1 = *excellent*, 5 = *poor*.
* $p < .01$.

jective ability, and recent experience components, because all of the loadings for each component derive from the same type of response items. That is, Component 1 is based exclusively on responses to the cumulative experience questions, Component 2 on responses to the self-rated ability questions, and Component 3 on responses to the recent experience questions.

As might be expected, Table 4 indicates that scores on the cumulative experience component increase with age, whereas those on the recent experience component decrease with age. Scores on the subjective ability component are negatively correlated with age but positively correlated with both spatial visualization performance and inductive reasoning performance. These latter results suggest that the overall self-appraisals of ability have some validity in that people with higher self-ratings perform better than people with lower self-ratings on tests of spatial visualization and, to a lesser extent, also on tests of the closely related inductive reasoning ability.

In contrast with Components 1 through 3, the pattern of loadings for the remaining components is more specific to the particular activity being described rather than to the type of response information requested. These components can therefore be inferred to represent experience with specific spatial

Table 2
Means and Standard Deviations of Responses to Spatial Experience Questionnaire (N = 343)

	Ability rating		Recent experience		Cumulative experience	
Item	*M*	*SD*	*M*	*SD*	*M*	*SD*
1. Imagining different arrangements of furniture or other objects	3.5	0.9	10.9	36.6	5.8	10.2
2. Considering how an object or building would look from a different viewing position	3.3	1.1	7.2	21.0	4.3	8.4
3. Devising efficient ways of packing or loading a box or car trunk	3.8	0.9	6.8	17.0	5.0	8.7
4. Following instructions for the assembly of furniture, toys, models, and so on	3.5	1.1	5.8	17.2	4.9	8.6
5. Visualizing travel directions from a verbal description	3.6	1.0	5.9	11.6	6.2	9.4
6. Designing or making clothes according to patterns	2.7	1.3	3.6	14.5	4.0	10.0
7. Producing or interpreting technical drawings (e.g., blueprints) of three-dimensional objects	3.0	1.3	5.7	18.9	3.4	7.7
8. Performing paper-folding activities such as origami	2.7	1.1	0.8	2.2	1.2	3.7
9. Solving piece-assembly games such as jigsaw puzzles	3.4	0.9	1.9	4.0	3.5	7.2
10. Working on spatial-manipulation puzzles like Rubik's Cube	2.5	0.9	0.9	3.4	1.2	4.1

Table 3
Component Loadings from Principal-Components Analysis of Questionnaire Responses After Varimax Orthogonal Rotation (N = 343)

Item	C1	C2	C3	C4	C5	C6	C7	C8	h^2
Abil1		.67							.58
REx1			.77						.72
CumEx1	.80								.72
Abil2		.65		.37					.60
REx2			.61	.43					.69
CumEx2	.78								.71
Abil3		.52							.52
REx3			.80						.68
CumEx3	.87								.77
Abil4		.51						.52	.64
REx4			.47	.41		.36			.57
CumEx4	.70								.63
Abil5		.31						.56	.44
REx5			.64					.33	.62
CumEx5	.63							.36	.68
Abil6		.42			.65				.66
REx6					.80				.68
CumEx6					.87				.79
Abil7		.57		.59					.75
REx7				.68					.58
CumEx7	.53			.59					.70
Abil8		.75				.36			.73
REx8						.41	.69		.75
CumEx8	.35						.79		.77
Abil9		.64							.54
REx9			.36			.57			.56
CumEx9	.66						.39		.69
Abil10		.71							.57
REx10						.76			.60
CumEx10	.55					.46			.60
Eigenvalue	6.13	3.44	2.64	1.96	1.79	1.32	1.21	1.03	

Note. C1: Non-specific cumulative experience; C2: Non-specific subjective ability; C3: Non-specific recent experience; C4: Perspective; C5: Clothes; C6: Puzzles 1; C7: Puzzles 2; C8: Directions. Abil = subjective ability; REx = recent experience; CumEx = cumulative experience.

activities. Based on the loading patterns, Components 4 through 8 have been labeled Perspective, Clothes, Puzzles 1, Puzzles 2, and Directions, respectively. Examination of Table 4 reveals that, among the specific components, only Component 4 (Perspective) and Component 8 (Directions) have significant correlations with the composite measure of spatial visualization performance.

One means of examining the validity of the experience assessments is to compare the responses of members of occupations assumed to require spatial visualization abilities with the responses of the entire sample. For this purpose, the data from 11 participants who reported their occupations as architects, civil engineers, or interior decorators were grouped together, and their scores on each of the components were computed.

Table 4
Correlations With Principal Components (N = 343)

Component	Age	Sex	Spatial visualization	Inductive reasoning	Perceptual speed
C1: Cumulative experience	.26*	−.06	−.08	−.12	−.09
C2: Subjective ability	−.18*	−.12	.36*	.21*	.10
C3: Recent experience	−.24*	.01	−.04	−.00	.00
C4: Perspective	−.11	−.23*	.17*	.02	−.03
C5: Clothes	.20*	.38*	−.11	−.02	−.02
C6: Puzzles 1	−.13	−.07	−.07	−.02	.03
C7: Puzzles 2	−.02	.05	−.07	−.09	−.02
C8: Directions	−.06	−.23*	.17*	.16*	.08

* $p < .01$.

The mean values for the individuals in this subsample were within one standard deviation of the sample mean for all components except Component 4, for which their mean component score was 2.29, with a range of 1.04 to 3.78. Component 4 is the Perspective component, with primary loadings on Activities 2, 4, and 7 (see Table 3). Comparisons of the estimated number of hours per month devoted to these activities revealed that the subsample estimates averaged 50.9 hours per month "considering how an object or building would look from a different position" (compared with 7.2 hours for the entire sample), 27.2 hours per month "following instructions for the assembly of furniture, toys, models, etc." (compared with 5.8 hours per month for the entire sample), and 50.7 hours per month "producing or interpreting technical drawings of three-dimensional objects" (compared with 5.7 hours for the entire sample). The finding that the estimates from people expected to have greater experience with certain spatial visualization activities were substantially higher than those from the entire sample enhances the credibility of the experience ratings.

Simultaneous Analysis of Age and Experience

A series of multiple regression analyses were conducted on the spatial visualization, inductive reasoning, and perceptual speed composite variables. The first analysis with each variable was a stepwise regression to determine which of the eight components from the questionnaire data had significant ($p < .01$) effects on the composite measures of cognitive performance. Three components (2, 4, and 8) were significant with the spatial visualization variable, one (Component 2) was significant with the inductive reasoning variable, and none was significant with the perceptual speed variable. The regression analyses were then repeated with only the significant components and age as predictors and were then repeated again for the spatial visualization and inductive reasoning variables with perceptual speed as an additional predictor. Identical analyses were conducted on composites based on the number of correct or right responses and on the number of incorrect or wrong responses, in addition to the primary analysis that was based on the number of right responses minus the number of wrong responses. Results from these analyses are summarized in Table 5.

The first point to note about Table 5 is that the absolute values of the variance estimates are larger with the composite based on number of right responses than with that based on the right–wrong scores. This is probably a reflection of the lower reliability of difference scores because all of the age correlations with the number of right scores were negative and all of those with the number of wrong scores were positive. (Note that this is inconsistent with what one would expect if there were a greater emphasis on accuracy than on speed with increased age.) A second point concerning the data in Table 5 is that although similar patterns are evident in the right–wrong and right scores, very few systematic effects were evident in the analyses based on the number of wrong responses.

It is evident in Table 5 that the age-related effects in both the spatial visualization and inductive reasoning variables were attenuated by statistical control of the questionnaire components and of perceptual speed. The proportion of age-associated variance for the spatial visualization variable was reduced from .139 to .083 after controlling the significant components from the questionnaire, to .085 after controlling perceptual speed, and to .048 after controlling both the questionnaire components and perceptual speed. Expressed in percentages, the age effect was reduced by 40.3% [(.139 − .083)/.139] after control of the questionnaire components, by 38.8% [(.139 − .085)/.139] after control of perceptual speed, and by 65.5% [(.139 − .048)/.139] after control of both. The age effects on the inductive reasoning variable were reduced less by controlling the questionnaire components and more by controlling perceptual speed. That is, the age effects were reduced 21.6% [(.088 − .069)/.088] after control of Component 2, 67.0% [(.088 − .029)/.088] after control of perceptual speed, and 77.3% [(.088 − .020)/.088] after simultaneous control of both Component 2 and perceptual speed.

As noted earlier, Component 2 reflects the individual's estimates of his or her level of ability across all activities and, because of the method used to identify components, is independent of the amount of cumulative or recent experience with any of the activities. A more appropriate evaluation of the contribution of relevant experience to the age effects on measures of spatial visualization should therefore be restricted to effects associated with Components 4 and 8. The total variance accounted for by age, Component 4, and Component 8 was .176, with .120 of that uniquely associated with age. The reduction of age-associated effects was therefore 13.7% [(.139 − .120)/.139]. After control of perceptual speed, the proportion of age-related variance was .085; this was reduced by 15.3%, to .072, after control of Components 4 and 8. Very similar estimates of the contributions of experience were derived from the measure of the number of right responses, as the reductions in age-related variance were 13.1% without considering perceptual speed and 14.1% for the speed-adjusted measures.

Multiple regression analyses were also conducted with Age X Component cross-product interaction terms entered after age and the eight questionnaire components. None of the interactions was significant (i.e., all $p > .20$) for either the right–wrong or the right scores for the inductive reasoning or perceptual speed variables. None of the interactions reached the .01 significance level with the right–wrong scores for the spatial visualization variable, but the interactions of age with Components 2, 4, and 8 approached significance (i.e., $p < .10$) with one or both of the right–wrong or the right scores. Another analysis was therefore conducted as a further check on the possibility that experience may have moderated age-related effects on spatial visualization. For this purpose, individuals were categorized into three groups on the basis of their scores on Component 2 (Subjective Ability), Component 4 (Perspective), and Component 8 (Directions). Regression equations relating age to the composite measure of spatial visualization performance were then computed for the individuals in each of these three groups. The resulting regression lines are illustrated in Figure 1 (Component 2), Figure 2 (Component 4), and Figure 3 (Component 8). Confidence intervals around the regression coefficients revealed that only the medium Component 2 and low Component 2 regression equations had significantly ($p < .01$) different slopes.

The important point to note in Figures 1, 2, and 3 is that although the regression lines for the individuals with higher

Table 5
Proportion of Variance Accounted for in Hierarchical Regression Analyses (N = 343)

Variable	Right–Wrong R^2	Right–Wrong Cum. R^2	Right R^2	Right Cum. R^2	Wrong R^2	Wrong Cum. R^2
Spatial visualization						
Age	.139*	.139	.206*	.206	.023	.023
Component 2	.129*	.129	.150*	.150	.051*	.051
Component 4	.028*	.157	.043*	.193	.004	.055
Component 8	.027*	.184	.035*	.228	.007	.062
Age	.083*	.267	.129*	.357	.011	.073
Perceptual Speed	.104*	.104	.085*	.085	.074*	.074
Age	.085*	.189	.149*	.234	.006	.080
Perceptual Speed	.104*	.104	.085*	.085	.074*	.074
Component 2	.107*	.211	.129*	.214	.039*	.113
Component 4	.031*	.242	.046*	.260	.006	.119
Component 8	.020*	.262	.028*	.288	.004	.123
Age	.048*	.310	.093*	.381	.001	.124
Inductive reasoning						
Age	.088*	.088	.157*	.157	.005	.005
Component 2	.044*	.044	.052*	.052	.016	.016
Age	.069*	.113	.131*	.183	.002	.018
Perceptual Speed	.227*	.227	.263*	.263	.087*	.087
Age	.029*	.256	.069*	.332	.000	.087
Perceptual Speed	.227*	.227	.263*	.263	.087*	.087
Component 2	.027*	.254	.032*	.295	.009	.096
Age	.020*	.274	.056*	.351	.001	.097
Perceptual speed						
Age	.081*	.081	.081*	.081	.006	.006

Note. Cum. R^2 = cumulative squared multiple correlation.
* $p < .01$ (for R^2 only).

values on the components are elevated relative to those with lower values (reflecting the significant main effects of these components), the slopes of the lines, and particularly those of the extreme groups, are nearly parallel. This suggests that the age effects are similar throughout the range of component values and implies that it is not the case that the magnitude of the age effects is attenuated among individuals with the greatest amount of experience or self-assessed ability.

Discussion

Before considering the implications of our results, it is important to note that the relation between age and spatial visualization performance evident in this study is consistent with that found in numerous earlier studies. For example, the correlation of −.37 between age and the composite measure of spatial visualization in this study is nearly identical to the median of −.39 for 18 correlations between age and spatial ability measures summarized in Table 12.1 of Salthouse (1985). This is noteworthy because the current sample is relatively select, with an average of over 15 years of education and a −.01 correlation between age and amount of education (Table 1).

The age-related effects on both the spatial visualization and inductive reasoning variables were substantially reduced after control of perceptual speed and self-rated ability. The findings with perceptual speed replicate those of earlier studies (e.g., Hertzog, 1989; Salthouse, Kausler, & Saults, 1988; Schaie, 1989) and are consistent with suggestions that at least some of the adult age differences in cognitive functioning are attributable to age-related reductions in the rate of processing information.

The effects associated with Component 2 are not easy to evaluate because it is not clear how the self-ratings of ability should be interpreted. In particular, it is difficult to determine the extent to which these ratings reflect personality characteristics such as self-confidence or feelings of self-efficacy, as opposed to actual levels of cognitive ability. If the self-ratings are merely alternative indicators of general cognitive ability, then they are of limited interest as potential mediators or moderators of age-related differences in cognitive functioning. Unfortunately, it was not possible to distinguish between these interpretations of the self-rating measures in our study.

The major conclusion implied from our findings is that many of the age-related effects on spatial visualization observed in this study, and presumably other studies, seem to be

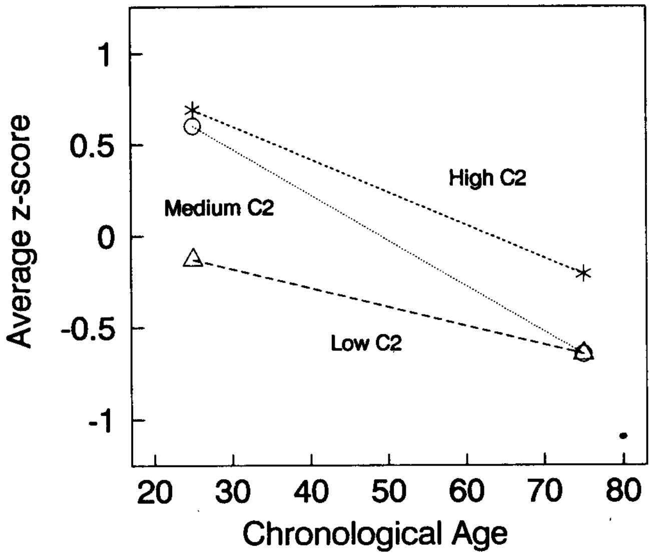

Figure 1. Regression lines relating composite spatial visualization score to age for individuals in the top, middle, and bottom thirds of the distribution of scores on Component 2 (C2; Subjective Ability).

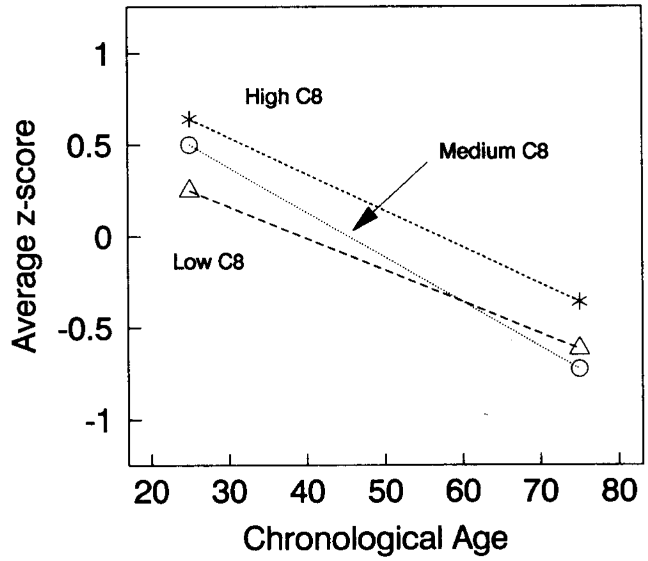

Figure 3. Regression lines relating composite spatial visualization score to age for individuals in the top, middle, and bottom thirds of the distribution of scores on Component 8 (C8; Directions).

relatively independent of the amount of relevant experience the individuals have received. That is, experiential factors appear to be responsible for only about 15% of the total age-related variance observed in measures of spatial visualization. However, acceptance of this conclusion is contingent on a number of assumptions that can each be challenged. It is therefore useful to consider arguments that can be raised in defense of three critical assumptions.

One assumption of our approach is that the responses to the questionnaire provide a valid indication of the actual experiences of the individuals. Evaluating the validity of self-report information of this type is always difficult, but there are several reasons to have confidence in our questionnaire results. First, the distributions of responses to the questionnaire items appear plausible, with average responses near the middle of the range for the subjective ability ratings and relatively small amounts of reported experience for most activities (see Table 2). Second, the principal-components analysis resulted in a coherent pattern of both general components (reflecting responses to each type of scale) and specific components (representing meaningful configurations of self-rated ability, recent experience, and cumulative experience for specific abilities). Third, members of occupations in which one would expect frequent usage of spatial visualization abilities had exceptionally high scores on the component concerned with spatial perspective.

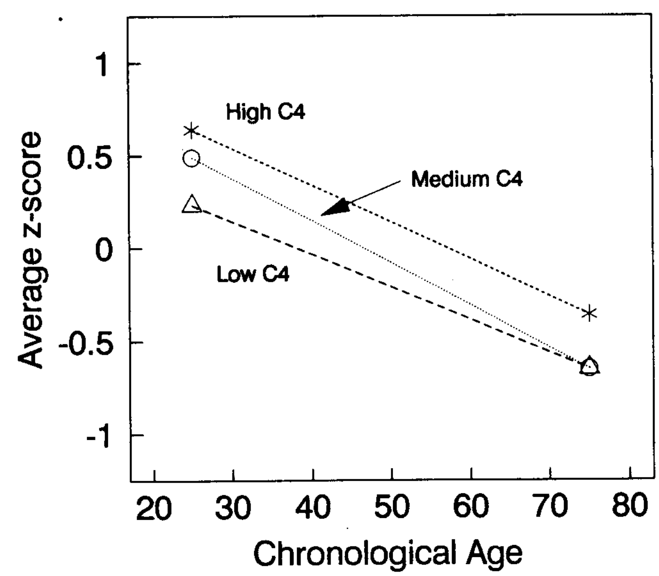

Figure 2. Regression lines relating composite spatial visualization score to age for individuals in the top, middle, and bottom thirds of the distribution of scores on Component 4 (C4; Perspective).

A second assumption implicit in our approach that could be challenged is that the range of experience was sufficient to reveal the expected influences of differential experience. Although it may be impossible to dispel all reservations about this assumption, it is important to point out that a considerable range of relevant experience was reported across participants in this study. To illustrate, the individuals in the top third of the distribution of values on Component 4 reported an average of 40 hr per month for performing the three constituent activities (i.e., 2, 4, and 7), whereas those in the bottom third of the distribution reported an average of only 6.5 hr per month for these activities. Despite this substantial difference in the amount of time spent performing what appear to be relevant activities, the data in Figure 2 indicate that the age trends in measures of spatial visualization performance for the two subgroups were nearly identical. It is clearly possible that individuals with more extreme levels of experience might be found and that differential age trends might be evident within that sample, but the range of naturally occurring experience with spatial visualization activities in our sample does appear unrepresentative of that expected in the general population.

A third assumption implicit in the approach used in this study is that the activities mentioned in the questionnaire are among the most relevant for spatial visualization abilities. An objection could be raised that the requirements of these activities are not sufficiently similar to what the examinee must do in the Paper Folding and Surface Development tests used in the assessment of spatial visualization ability to expect substantial relations between experience and spatial visualization performance. This is a plausible concern, but we have been unable to identify relatively common activities that appear to have greater relevance to the spatial visualization construct. Moreover, it is interesting to consider the implications for the disuse hypothesis of the difficulty of finding activities relevant to the abilities observed to decrease with increased age: If there are no activities that provide appropriate experience, then neither the concepts of use nor of disuse may be very meaningful with respect to the maintenance or decline of spatial abilities across the life span.

Additional objections to the current procedures could undoubtedly be raised, but it is noteworthy that results similar to those found in this study have previously been reported with quite different methodologies. For example, three studies have used a strategy of examining age trends in molecular, or basic, processes after equating individuals of different ages in the proficiency of a molar target activity. Charness examined unexpected recall of bridge hands among bridge players (Charness, 1979) and of chess configurations among chess players (Charness, 1981), and Salthouse examined measures of perceptual-motor speed among transcription typists (Salthouse, 1984). In each case, significant age-related declines were found in the measure of the molecular processes despite what can be assumed to be moderate to high amounts of relevant experience for most research participants.

Two studies examining the joint effects of age and reading habits on recall of prose material are also pertinent to the disuse perspective if it is assumed that experience with reading is relevant to the task of recalling prose material. In a 1986 study, a questionnaire was administered to assess the number of hours per week devoted to reading different types of material and the individual's preferences for various kinds of reading (Rice & Meyer, 1986). Although several of the summary scores derived from a principal-components analysis were significantly related to both age and total recall performance, there was no evidence that the age effects varied as a function of the amount of reading experience. A later study by the same investigators (Rice, Meyer, & Miller, 1988) involved the simultaneous examination of prose recall performance and degree of reading activity, as determined from analyses of diaries. Unfortunately, Rice et al. did not report the extent to which the age-related effects in recall were attenuated by controlling for amount of reading experience, but they did indicate that the effects of age and educational level were much greater than those associated with reading habits.

In summary, the findings of our study, in conjunction with the results of the studies just reviewed and the occupation-specific studies described earlier, appear inconsistent with the disuse perspective. Not only are the age-related effects generally similar across different levels of presumably relevant experience (this study and probably the studies of Rice & Meyer, 1986, and Rice et al., 1988), but they appear to be substantial even among samples selected to be equivalent with respect to occupation (e.g., Glanzer & Glaser, 1959; Glanzer, Glaser, & Richlin, 1958; Salthouse et al., 1990) or to level of molar ability (e.g., Charness, 1979, 1981; Salthouse, 1984). The seemingly inescapable conclusion from this body of evidence is that many of the age-related effects on measures of relatively basic abilities are largely independent of the amount of relevant experience.

We hasten to point out, however, that this conclusion does not imply that there are not positive benefits of experience or that increased age in adulthood is inevitably associated with declining levels of competence. More extensive experience frequently results in greater knowledge (both declarative and procedural), better discrimination between relevant and irrelevant information, more successful execution of complex activities, and perhaps more effective monitoring and deployment of basic abilities. What remains to be resolved is the dynamic relation between the efficiency of basic abilities and the operation of these higher order processes, and whether, and if so how, this relationship changes with age.

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