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Why Do Adult Age Differences Increase With Task Complexity?

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A total of 451 adults between 18 and 80 years of age participated in 2 studies conducted to investigate causes of the phenomenon that adult age differences in cognitive performance frequently increase with increased task complexity. All Ss performed 4 cognitive tasks at each of 3 levels of complexity. The strongest predictors of performance on the intermediate and complex versions of the tasks were performance on the simpler versions of the same tasks and a composite measure of working memory. It was concluded that one cause of the age-complexity phenomenon is that more complex cognitive tasks place greater demands on a working-memory resource that declines with increased age.

It has frequently been observed that the performance of older adults is affected more than that of young adults by increases in the complexity[1] of a cognitive task. For example, Birren (1956), Clay (1954), Crowder (1980), Jones (1959), Kay (1955), and Welford (1958) have all noted that older adults seem to be more affected than young adults as the conditions of a task become more complex and demanding. Most of these early observations were informal, because an objective and widely accepted definition of the concept of complexity is not yet available. In the last several years, however, Salthouse and his colleagues have manipulated task characteristics presumed to increase the number of processing operations required to perform the task. For example, in various studies the manipulations have included the number of stimulus frames containing to-be-integrated stimulus fragments (Salthouse, 1988; Salthouse & Mitchell, 1989; Salthouse, Mitchell, & Palmon, 1989), the number of elements in each term of geometric analogy problems (Salthouse, 1987, 1988); the number of folds of a piece of paper prior to a simulated hole punch in paper-folding problems (Salthouse, 1988; Salthouse, Mitchell, Skovronek, & Babcock, 1989), and the number of premises presented before a question concerning the relations between two terms in integrative reasoning problems (Salthouse, Legg, Palmon, & Mitchell, 1990; Salthouse, Mitchell, Skovronek, & Babcock, 1989). In each of these cases, the age-related differences in a measure of decision accuracy were found to increase with increases in the number of hypothesized processing operations.

The age-complexity phenomenon is important for at least two distinct reasons. One reason is that the phenomenon raises questions about the meaningfulness of across-task comparisons unless there is some basis for believing that the tasks being compared are at least roughly equivalent in processing complexity. That is, an implication of the age-complexity phenomenon is that the magnitude of age-related differences on a cognitive task may be determined not simply by what kind of processing is involved, but also by how much processing is required. Attempts to identify qualitatively distinct types of processing impairments (e.g., those involved with verbal or spatial information) associated with increased age might therefore be suspect if the tasks are not similar in their quantitative demands on processing.

The second reason why the age-complexity phenomenon is important is that identification of the causes of this phenomenon may contribute substantially to understanding the causes of adult age differences in cognition. Specifically, if one knew why age differences often become larger when tasks increase in complexity, then one would likely be in a better position to explain the existence of age differences at any level of task complexity.

This point can be elaborated by considering how psychometric tests serve to differentiate among people of varying levels of ability. At least with power as opposed to speed tests, the identification of ability differences is largely based on the average difficulty of the items an individual can answer correctly. Item difficulty can be manipulated in a variety of ways, but a common method consists of varying the number of required processing operations, or what is referred to here as *complexity*. Unpacking or disaggregating cognitive performance according to complexity level may therefore provide insight into the precise nature, and possibly the causes, of individual differences in cognitive functioning.

A primary goal of the current project was to attempt to evalu-

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[1] Some authors have used the term age-complexity phenomenon to refer to the finding that the response speeds of older adults are often roughly proportional to those of young adults across a variety of experimental conditions. However, because complexity is seldom defined independent of the performance of young adults in studies of speeded performance, and because the age-complexity phenomenon seems broader than the approximate proportionality evident in a single dependent variable, the age-complexity term is used here to refer to the tendency evident in many performance measures for the age differences to increase in absolute magnitude with increases in the presumed complexity of the to-be-performed task.

ate the relative importance of three different factors as potential determinants of the age-complexity phenomenon: (a) processing components present in simpler versions of the cognitive task; (b) measures presumed to reflect relatively general processing resources, such as working memory or speed of processing; and (c) other unmeasured factors that are negatively related to age.

One hypothesis to account for the age-complexity phenomenon is that it arises because more complex versions of cognitive tasks require more repetitions of critical processing operations. To illustrate, if, for whatever reason, there is a small age-related difference in error probability for a single operation, then the accuracy of older adults can be expected to decrease more than that of young adults as complexity is increased by requiring that the critical operation be executed a greater number of times. A key characteristic of this interpretation is that no new age-sensitive processes are presumed to be involved in the more complex versions of the tasks; the magnitude of the age-related differences is nevertheless expected to increase because the accumulated errors will be greater for older adults than for young adults. This interpretation thus leads to the prediction that a primary determinant of performance in a complex version of a task will be the individual's performance in simpler versions of that task.

A second interpretation of the age-complexity effect is that as tasks become more complex they place more demands on a limited processing resource such as working memory. That is, when the number of operations increase, there may also be a greater reliance on working memory to preserve the products of early operations during the execution of later operations. Age-related performance differences might therefore increase if some aspect of working memory decreases with age, such that the older individual is less able to deal with greater demands for concurrent storage and processing. This interpretation leads to the prediction that performance in complex versions of a task should be influenced by the individual's level of working memory (or other hypothesized processing resources), even after partialling out the contributions of performance in simpler versions of the task.

A third hypothesis to account for the age-complexity effect is that as tasks become more complex, they require something distinct from that required by simpler versions of the task but not represented by the particular measures of working memory or other processing resources available in the study. For example, as the number of operations involved in a task increases, factors such as strategy effectiveness, efficiency of metacognitive functioning, perseverance, or sustained concentration may become progressively more important. If these or other factors not reflected in the processing resource measures are negatively related to age, then one might expect appreciable influences of age on complex performance even after controlling for all of the effects associated with performance on simpler versions of the task.

A number of tentative guidelines can be proposed for research attempting to evaluate the relative importance of different factors to a phenomenon such as the age-complexity effect. One recommendation is that the samples should be moderately large to provide reasonable power to detect the influence of one variable after the influence of other variables has been statistically controlled. A second desirable feature is that the research should involve a variety of cognitive tasks to evaluate the possibility that the factors responsible for the phenomenon might vary as a function of the particular tasks under investigation. If the measures from the different tasks are found to have moderate to high correlations with one another, then this characteristic may also allow powerful analyses at the level of latent constructs. Finally, to assess the generalizability of the results, it is always desirable to replicate the study in an independent sample of individuals. An attempt was made to adhere to these guidelines in the current project by conducting two studies, each with over 220 adults between 20 and 80 years of age, who performed four different cognitive tasks at three levels of task complexity.

The four cognitive tasks are illustrated in Figure 1. Although not represented in the figure, each problem was accompanied by a space for the respondent to indicate whether the answer to the problem was *yes* or *no.* The decisions concerned (a) the answer to the question in the reasoning task, (b) whether the transformations from the first to the second terms matched those from the third to the fourth terms in the analogies task, (c) whether the two arrows would point at each other when the squares were folded into a cube in the cube assembly task, and (d) whether the displayed sequence of folds and hole location would result in the portrayed pattern of holes in the paper-folding task. Problems in the top row correspond to the simplest level of complexity (with one reasoning premise, one analogy element per term, one paper fold, or two required folds in the cube assembly task), and those in the second and third rows illustrate successively higher levels of complexity.

The tasks illustrated in Figure 1 differ in certain respects from the kinds of tests used in psychometric evaluations of cognitive ability, but there are two reasons to believe that similar constructs are being assessed. First, the relations of age, speed, and working memory on these tasks have been found to be very similar to those evident on standard psychometric tests such as the Raven's Progressive Matrices and the Shipley Abstraction Test (compare the results in Study 1 with those in Studies 2 and 3 in Salthouse, 1991). Second, the correlations between performance on several of these tasks and performance on standard psychometric tests are nearly as high as are the correlations between the psychometric tests themselves. To illustrate, in a recent unpublished project involving 305 adults similar to those participating in this project, the correlations between performance in the integrative reasoning and analogies tasks with the Schaie-Thurstone Adult Mental Abilities Test (STAMAT; Schaie, 1985) Space Test were .43 and .50, respectively, and those with the STAMAT Reasoning Test were .54 and .57, respectively. The correlation between the measures from the two STAMAT tests in that study was .53. Because performance in these tasks is influenced by the same variables as those influencing performance in psychometric tests, and because the correlations between measures from these tasks and those from psychometric tests are similar in magnitude to the correlations between measures from psychometric tests, it therefore seems reasonable to expect that results from these tasks will be generalizable to more conventional psychometric tests.

Two analytical methods were selected to provide complemen-

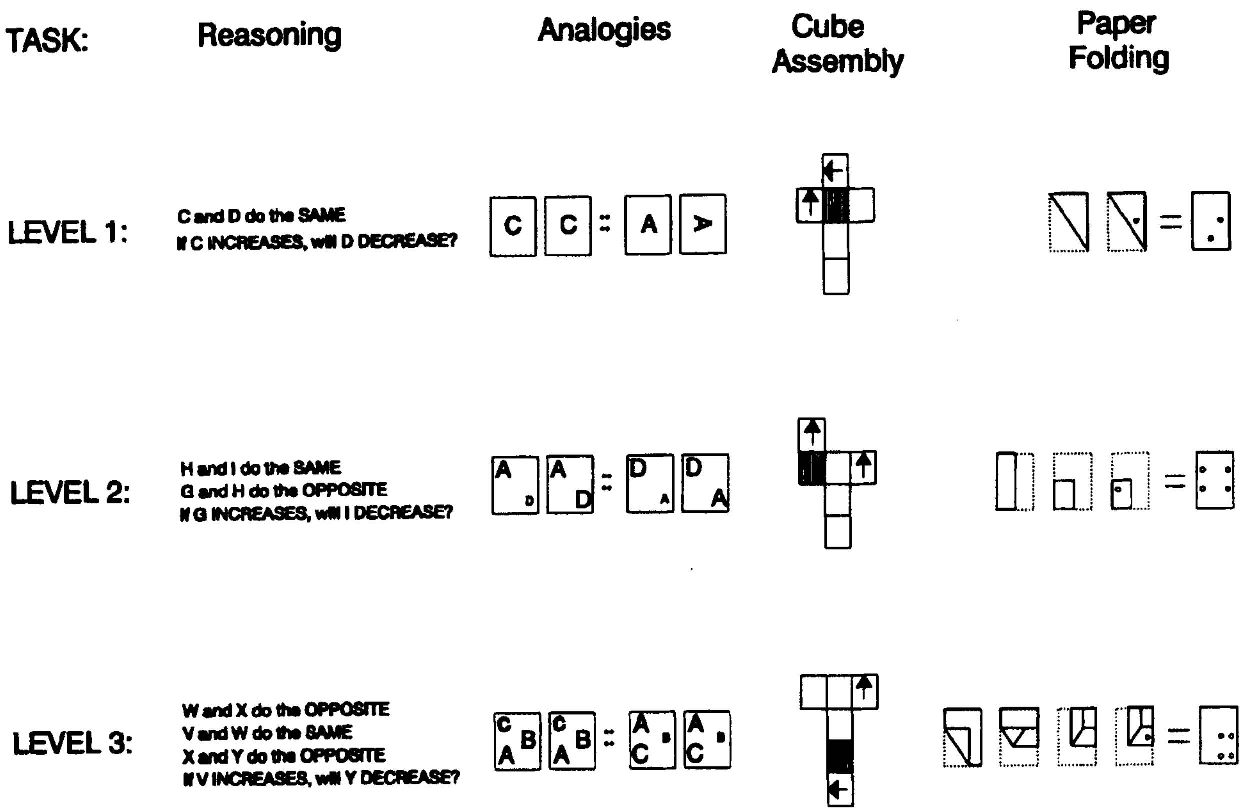

Figure 1. Illustration of sample problems at the three levels of complexity in the four cognitive tasks.

tary measures of the strength of the association between two variables after considering the influence of other variables. Hierarchical regression procedures yield estimates of the proportion of variance in one variable shared with that of another variable when the linearly related influence of other variables has been statistically controlled. Path analysis procedures can be viewed as providing estimates of the degree to which one variable changes as a function of changes in other variables. Path coefficients are essentially standardized regression coefficients but differ primarily in that, unlike regression, in path analysis the same variable can function as both a cause (or predictor) and a consequence (or criterion). With neither analytical method is the goal in this project to determine the combination of parameters that provides the optimum fit to one particular set of data. Instead, the proportion-of-variance measures and the path coefficients will be used as estimates of the magnitude of the relations among variables for a specific combination of tasks and subjects. Conclusions from the research will then be based on the overall pattern evident across the two analytical methods, four tasks, and two subject samples.

In addition to the four cognitive tasks, all research participants also performed four tasks designed to provide two measures of each of two potentially important processing resources. Measures of working memory were included because it seems plausible that increasing the number of processing operations required to perform a task increases the demands on working memory. The tasks used to measure working memory were the computation span and listening span tasks described by Salthouse and Babcock (1991). Both involved the auditory presentation of information (arithmetic problems or sentences), the participant carrying out some processing on the presented material (i.e., solving the arithmetic problem or answering a question about the sentence), and then the research participant recalling the last item (i.e., digit or word) from each problem or sentence. Unlike the cognitive tasks, in which working memory is postulated to be only one of several determinants of task performance, these tasks were specifically designed to assess the individual's ability to simultaneously remember and process information.

The other two tasks measured perceptual comparison speed, because Salthouse and Babcock (1991) found that a large proportion of the age differences in the computation span and listening span measures of working memory were apparently mediated by age-related reductions in perceptual comparison speed. The two speed tasks—the letter comparison and pattern comparison tasks used by Salthouse and Babcock (1991)—required the subjects to decide as rapidly as possible whether two strings of letters or two patterns of line segments were the same or different.

The availability of measures of working memory and perceptual comparison speed also allows an examination of the influence of each of these constructs on the magnitude of the age differences in measures of cognitive functioning collapsed across complexity levels. The relevant relations are represented in Figure 2. Of particular interest is the magnitude of the relation between age and cognition (Path 1) after taking into account the relations among speed, working memory, and cognition. Analyses based on composite cognitive measures (averages of *z* scores across the four tasks) from the current studies were recently reported by Salthouse (1991). The major finding in that article was that the age-related influence on cognition was greatly attenuated after statistical control of measures of speed and working memory. These earlier analyses are extended in the present report by determining whether similar patterns are evident when the data are examined at the level of individual cognitive tasks.

Method

Subjects

All subjects were recruited from newspaper advertisements requesting volunteers to participate in projects concerned with various aspects of memory. Each individual received $10.00 for participating in a single session lasting approximately 90 min. A total of 228 adults (103 women and 125 men) participated in Study 1, and 223 (113 women and 110 men) participated in Study 2. The number of individuals per decade in each study ranged from 31 to 52, and the percentage of women in each decade ranged from 36% to 58%, with a minimum of 12 individuals of each sex in each decade. Means (and standard deviations) of selected characteristics of the samples were as follows: age, Study 1 = 50.3 (17.7), Study 2 = 49.2 (17.6); self-reported years of formal education, Study 1 = 15.4 (2.5), Study 2 = 15.3 (2.7); and self-reported health (on a scale ranging from 1 for *excellent* to 5 for *poor*), Study 1 = 2.2 (1.2), Study 2 = 2.0 (1.1). Correlations between age and amount of education were .05 in Study 1 and .03 in Study 2, and those between age and self-rated health were .20 ($p < .01$) in Study 1 and .02 in Study 2. Although the age–health correlation was statistically significant in Study 1, there was little effect on the relations between age and measures of cognitive performance after adjusting for the age differences in health status and, consequently, this variable was ignored in all subsequent analyses.

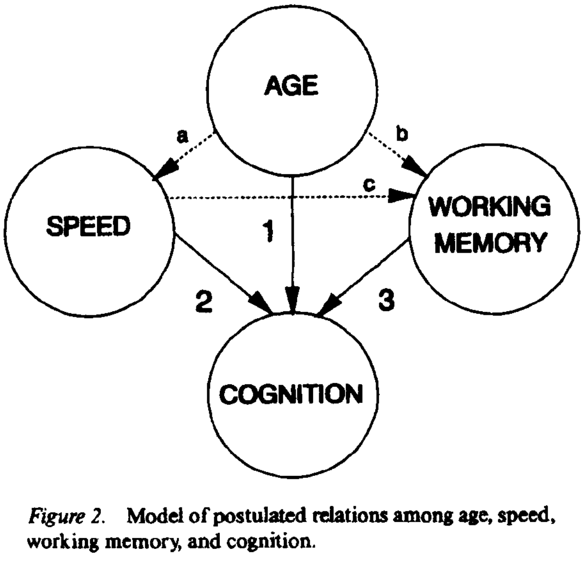

Figure 2. Model of postulated relations among age, speed, working memory, and cognition.

Procedure

The tasks in each study were performed in the same order by all subjects. The order of tasks in Study 1 was the Wechsler Adult Intelligence Scale—Revised (WAIS–R) Digit Symbol Substitution Test (Wechsler, 1981), letter comparison, pattern comparison, computation span, listening span, cube assembly, reasoning, analogies, and paper folding. Tasks in Study 2 were presented in the same order, except that the last four tasks were reasoning, paper folding, analogies, and cube assembly. Results from the Digit Symbol Substitution Test are not reported here, because they are described in a separate report focusing on age-related differences in that test (Salthouse, 1992). Materials for all tasks were assembled in booklets in which subjects wrote their responses.

The letter comparison task consisted of three separately timed (30 s each) presentations of 64 pairs of three, six, or nine letters. Half of the letter pairs were identical, and half differed in the identity of one letter. Each pair of letters was separated by a line on which the subject was to write the letter S (for *same*) or D (for *different*) as rapidly as possible. The measure of performance in this task was the average number of items answered correctly across the three trials.

The pattern comparison task was similar to the letter comparison task but consisted of geometric patterns instead of strings of letters. The two patterns in the pair contained three, six, or nine line segments, and each was separated by a line on which the subject was to write the letter S (for *same*) or D (for *different*) as rapidly as possible. Half of the pattern pairs were identical, and half differed in the position of one line segment. The performance measure was the average number of pairs correctly classified across the three 30-s trials.

The computation span and listening span tasks both required the subject to carry out specified processing while also remembering target information. The processing in the computation span task involved the solution of auditorily presented arithmetic problems, and the to-be-remembered information was the last digit in each problem. Processing in the listening span task involved answering written questions about auditorily presented sentences, and the to-be-remembered information was the last word in each sentence. Three alternative answers for each problem or sentence were provided in the test booklet, and the subject indicated his or her decision by writing a mark next to the selected alternative. In both tasks, three trials each were presented with sequences of one to seven arithmetic problems or sentences. Spans were determined by the largest number of items recalled in the correct sequence on at least two of the three trials, given that the processing (i.e., the arithmetic or the answers to the questions about the sentences) was also performed correctly. Further details of the tasks are presented in Salthouse and Babcock (1991).

Sample problems in the four cognitive tasks are illustrated in Figure 1. Each task was preceded by an instruction page containing two sample problems and an explanation of the solution of those problems. Test problems were presented on pages in the booklet, with an average of about 12 problems per page. The three complexity levels were intermixed in Study 1 with one problem of each complexity level in every set of three problems. Subjects were allowed 4 min to complete as many of the 72 problems as possible. In Study 2, the 24 problems at each complexity level were grouped in separate sets, and subjects were allowed 90 s to complete as many items as possible within each set. In both studies speed and accuracy were emphasized equally, and subjects were encouraged not to skip any problems but to guess if they were not sure about the answer to a particular problem.

Results

Before considering the measures of cognitive performance, the relations among age, speed, and working memory reported

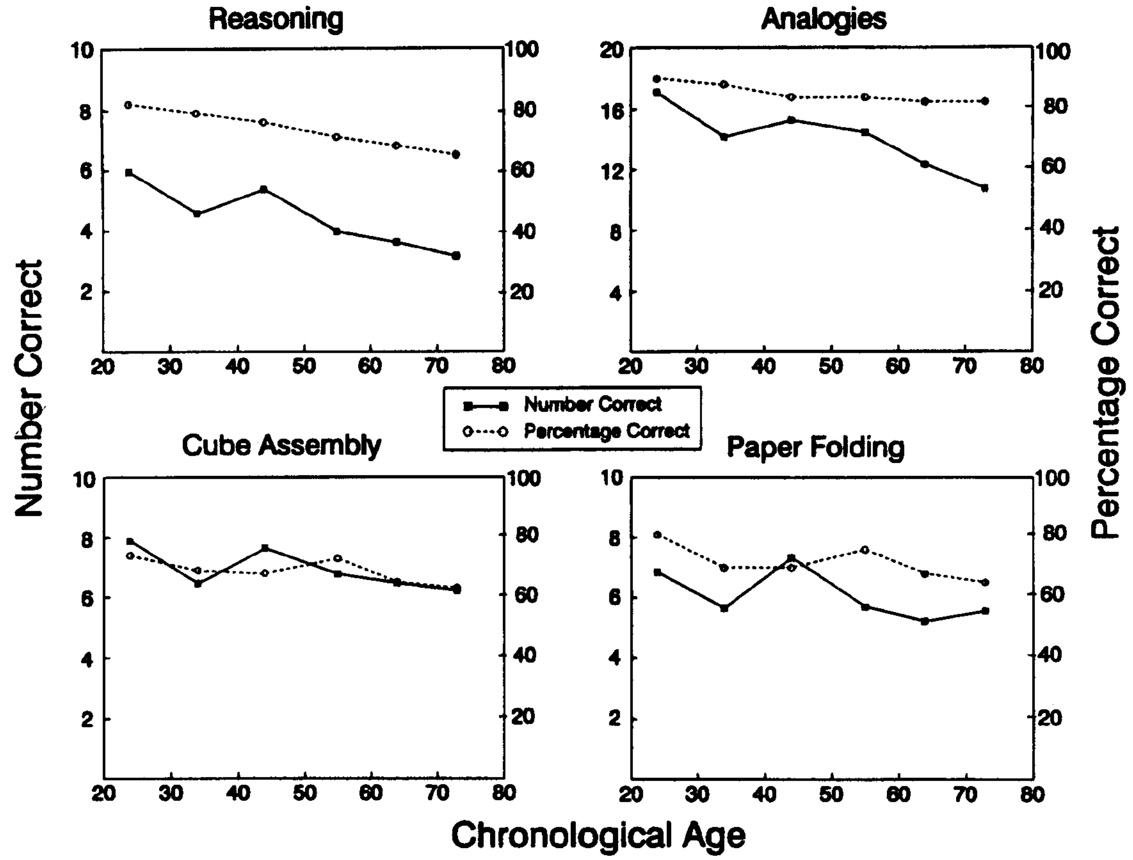

Figure 3. Performance in terms of number of items correct and percentage of overt responses answered correctly in the four cognitive tasks in Study 1.

in Salthouse (1991) are reviewed. The initial step in the analysis of these variables consisted of creating composite measures of speed and working memory by averaging the *z* scores from the two relevant measures for each subject. This aggregation was considered reasonable because the correlations between the two perceptual speed measures were .79 in Study 1 and .80 in Study 2, and those between the computation span and listening span measures of working memory were .63 in Study 1 and .62 in Study 2. Furthermore, factor analyses (promax rotation specifying two factors) revealed patterns consistent with the hypothesized constructs. That is, in each study the two perceptual speed measures had loadings of .91 or greater on the perceptual speed factor and loadings of .06 or smaller on the working-memory factor, whereas the two working-memory measures had loadings of less than .16 on the perceptual speed factor and loadings of .78 or greater on the working-memory factor.

Hierarchical regression analyses were next conducted with age and the composite perceptual speed measure as predictors of working memory. The R^2 for age in predicting working memory performance was .254 before considering speed and .014 after control of speed in Study 1, with values of .208 and .012, respectively, in Study 2. Estimates of the standardized coefficients for the paths labeled a, b, and c in Figure 2 were −.669, −.154, and .450, respectively, in Study 1, and −.569, −.120, and .510, respectively, in Study 2. Both sets of results are therefore consistent with findings of Salthouse and Babcock (1991) that much of the age-related differences in these measures of working memory are apparently mediated by age-related differences in perceptual comparison speed.

Two measures of cognitive performance were obtained for each subject in each cognitive task. One measure was the total number of items answered correctly, and the other was the percentage of items with overt responses (i.e., excluding omissions) answered correctly. Means of these measures in each age decade are displayed in Figure 3 for Study 1, and in Figure 4 for Study 2.

Exploratory factor analyses (promax rotation, factor extraction by criterion of eigenvalue greater than 1) were conducted on the number correct and the percentage correct measures at each level of complexity for the four tasks in both Studies 1 and 2. Two possible outcomes of these analyses would have been especially interesting in the present context. One would have been a discovery that the measures loaded on a single factor, suggesting that they represented a common construct of cognitive functioning. An even more intriguing result would have been a pattern in which the factors were defined by measures of the same complexity level from different tasks.

Neither of these outcomes was apparent in any of the four factor analyses. Instead, the three or four factors identified in

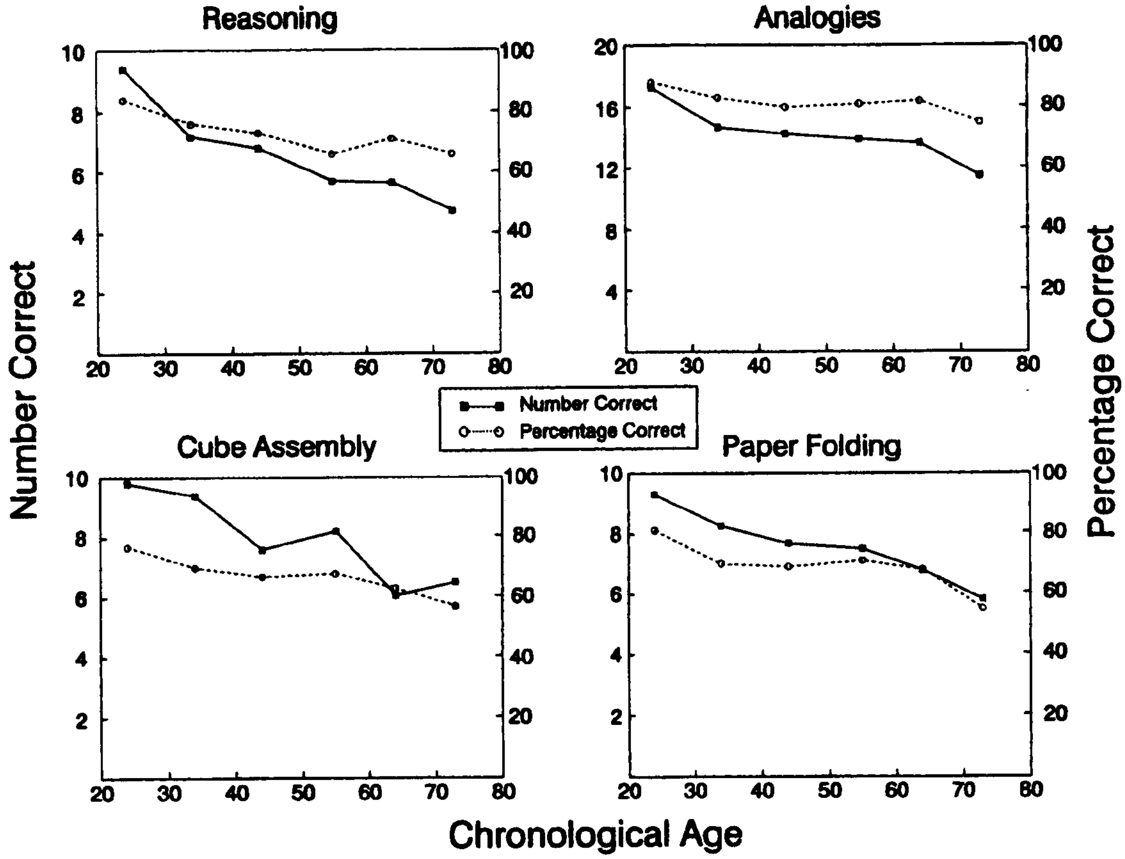

Figure 4. Performance in terms of number of items correct and percentage of overt responses answered correctly in the four cognitive tasks in Study 2.

the analyses seemed to be determined by the three measures from the same task, regardless of the level of complexity. Because these results imply that performance is highly task-specific, all subsequent analyses were conducted at the level of individual tasks.[2]

Results from the hierarchical regression analyses on the two measures of performance from each task are summarized in Table 1. The first column within each set indicates the cumulative R^2 after entering the variable, and the variables that preceded it, in the regression equation. The second column contains the increment in R^2 associated with the addition of the second or third variable, and the third column indicates the F value evaluating the significance of the first, second, or third variable in the regression equation. It is apparent in the measures of every task that introducing working memory and speed into the regression equation before age greatly reduces the magnitude of the age-related influence on cognitive performance. To illustrate, the age-related variance was greater than 5% in 14 of the 16 comparisons in Table 1 before statistical control of the speed measure, but was greater than 5% in only 2 of the 16 comparisons after removing the speed-related variance.

Standardized coefficients of the path model illustrated in Figure 2 are summarized in Table 2. (Standardized coefficients are used because the interesting comparisons are across variables and because the absolute units of measurement are assumed to be relatively arbitrary.) Correlations between age and the relevant cognitive measures are also reported in Table 2 to allow comparisons of the total age effect (i.e., the sum of direct[3] and indirect or mediated influences) with the direct effect obtained after estimating the indirect relations among age, speed, and working memory. Across all 16 entries, the average direct effect of age (i.e., −.143) is only 40.6% of the average total age effect (i.e., −.352), indicating that almost 60% of the age-related effects are presumably mediated through reductions of work-

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[2] The discovery of weak relations among measures at the same level of complexity from different cognitive tasks also made it impractical to use structural modeling techniques (e.g., LISREL) in which the measures could be assumed to be indicators of the same construct of cognition or complexity. One possible reason for these weak relations is that the performance measures were not very reliable, because the number of relevant observations at each complexity level for a given task was quite small. That is, the mean (in the total sample) number of items answered correctly at each complexity level ranged from 2.7 to 13.1 for the reasoning, paper-folding, and cube assembly tasks, and from 7.9 to 20.6 for the analogies task.

[3] Note that *direct* in this context means that the relation is not mediated by other variables represented in the model. It is, of course, possible that the relation is mediated by other unspecified variables not incorporated in the model.

Table 1

Results of Hierarchical Regression Analyses Predicting Number of Correct Answers and Percentage of Responses Answered Correctly

	Reasoning			Analogies			Cube assembly			Paper folding			*M*
Variable	R^2	Incr. R^2	F	R^2	Incr. R^2	F	R^2	Incr. R^2	F	R^2	Incr. R^2	F	Incr. R^2
						Study 1 (n = 228)							
Number correct													
Age	.164		44.25*	.189		52.76*	.019		4.42	.037		8.76*	.102
Speed	.180		50.64*	.349		120.57*	.023		5.32	.035		8.28*	.147
Age	.202	.022	6.16	.349	.000	0.20	.025	.002	0.45	.043	.008	1.71	.008
Working memory	.113		31.35*	.177		52.57*	.013		2.95	.010		2.28	.078
Age	.187	.074	20.51*	.244	.067	19.86*	.022	.009	2.04	.037	.027	6.44	.044
Speed	.180		50.88*	.349		121.40*	.023		5.30	.035		8.25*	.147
Working memory	.191	.011	3.20	.356	.007	2.71	.024	.001	0.20	.035	.000	0.05	.005
Age	.209	.018	5.05	.357	.001	0.04	.026	.002	0.37	.043	.008	1.83	.007
Percentage correct													
Age	.121		31.18*	.123		31.57*	.056		13.51*	.069		16.76*	.092
Speed	.136		36.11*	150		40.20*	.079		19.38*	.088		21.92*	.113
Age	.151	.015	4.01	.161	.011	3.11	.082	.003	0.72	.094	.006	1.36	.009
Working memory	.265		82.40*	.199		57.37*	.111		28.32*	.113		29.13*	.172
Age	.276	.011	3.28	.220	.021	6.08	.118	.007	1.65	.125	.012	2.99	.013
Speed	.136		42.16*	.150		43.41*	.079		20.19*	.088		22.74*	.113
Working memory	.272	.136	41.92*	.222	.072	20.99*	.122	.043	10.95*	.128	.040	10.24*	.073
Age	.276	.004	1.47	.227	.005	1.35	.123	.001	0.14	.130	.002	0.52	.003
						Study 2 (n = 223)							
Number correct													
Age	.252		74.43*	.225		63.99*	.125		31.49*	.197		54.09*	.200
Speed	.388		145.73*	.413		158.19*	.101		25.83*	.209		61.61*	.278
Age	.414	.026	9.67*	.425	.012	4.68	.142	.041	10.62*	.254	.045	13.20*	.031
Working memory	.295		184.13*	.338		122.66*	.028		7.03*	.076		21.11*	.184
Age	.377	.082	28.84*	.393	.055	19.95*	.125	.097	24.33*	.204	.128	35.13*	.091
Speed	.388		153.68*	.413		172.21*	.101		25.84*	.209		61.44*	.278
Working memory	.429	.041	16.05*	.468	.055	22.97*	.102	.001	0.34	.209	.000	0.02	.024
Age	.447	.018	7.15*	.475	.007	2.63	.146	.044	11.36*	.255	.046	13.54*	.029
Percentage correct													
Age	.104		25.77*	.083		20.10*	.178		47.88*	.203		56.12*	.142
Speed	.081		20.12*	.127		32.31*	.123		33.64*	.169		48.43*	.125
Age	.117	.036	9.08*	.136	.009	2.25	.193	.070	19.02*	.234	.065	18.60*	.045
Working memory	.149		39.92*	.309		98.49*	.155		44.36*	.290		96.99*	.226
Age	.177	.028	7.29*	.310	.001	0.51	.229	.074	21.17*	.343	.053	17.70*	.039
Speed	.081		21.48*	.127		40.31*	.123		35.08*	.169		56.22*	.125
Working memory	.153	.072	19.16*	.309	.182	57.82*	.174	.051	14.43*	.300	.131	43.64*	.109
Age	.177	.024	6.47	.310	.001	0.42	.230	.056	15.80*	.343	.043	14.33*	.031

Note. Incr. R^2 = increment in R^2 associated with the addition of the second or third variable.
* $p < .01$.

Table 2
Path Coefficients for the Paths Illustrated in Figure 2

Coefficient	Reasoning	Analogies	Cube assembly	Paper folding	*M*
		Study 1			
Number correct					
Age correlation	−.405*	−.435*	−.139	−.193*	−.293
1 (age)	−.191	−.015	−.057	−.127	−.098
2 (speed)	.239*	.546*	.100	.126	.253
3 (working memory)	.119	.119	.032	−.039	.068
Percentage correct					
Age correlation	−.348*	−.350*	−.237*	−.263*	−.300
1 (age)	−.099	−.098	−.034	−.064	−.074
2 (speed)	.039	.136	.114	.117	.101
3 (working memory)	.491*	.356*	.280*	.265*	.348
		Study 2			
Number correct					
Age correlation	−.502*	−.474*	−.353*	−443*	−.443
1 (age)	−.169*	−.100	−.265*	−.271*	−.201
2 (speed)	.398*	.428*	.221*	.341*	.347
3 (working memory)	.258*	.315*	−.092	−.052	.107
Percentage correct					
Age correlation	.323*	−.289*	−.422*	−.450*	−.371
1 (age)	−.196*	−.046	−.296*	−.262*	−.200
2 (speed)	−.029	−.002	.023	−.008	−.004
3 (working memory)	.348*	.594*	.271*	.471*	.421

Note. Coefficients a, b, and c were −.669, −.154, and .450, respectively, in Study 1, and −.569, −.120, and .510, respectively, in Study 2.
* $p < .01$.

ing memory or speed. It should also be noted that the coefficients for the relation between age and the measure of cognition (i.e., Path 1) are generally smaller than those between either speed (i.e., Path 2) or working memory (i.e., Path 3) and cognition. Finally, it can be seen that the influence of speed was greater than that of working memory with the number correct measure but that this pattern was reversed with the percentage correct measure. These results are consistent with the view that the number of items answered correctly is determined largely by the speed with which the individual can work, whereas the percentage of attempted items answered correctly is influenced more by the individual's working-memory abilities.

All of the results just described are consistent with those based on analyses of composite measures of cognition reported in Salthouse (1991). It can therefore be concluded that although there is some variation in the magnitude of the relations among age, speed, working memory, and cognitive performance across different cognitive tasks, the same general pattern is still evident when the analyses are conducted at the level of individual tasks. At least for these cognitive tasks and these samples, much of the age-related reduction in cognitive performance appears to be mediated by age-related reductions in working memory, which in turn appear to be largely mediated by age-related reductions in speed of processing, as that construct is assessed by the current measures of perceptual comparison speed.

To examine the relation between age and the magnitude of performance decline associated with increases in task complexity, it is first necessary to exclude the data from subjects who fail to perform successfully at the simplest level of complexity. This is essential because it is impossible to exhibit progressively lower levels of performance with increased task complexity if performance is already very low in the simplest, or least complex, version of the task. All analyses that follow are therefore restricted to data from subjects in each task with accuracy of at least 85% correct responses in the simplest version of the task. This is an arbitrary value, but it was selected to be high enough to ensure an adequate range of performance above the 50% chance level, and yet still low enough not to exclude too many individuals. The number of subjects satisfying this criterion varied across tasks and decreased with advancing age. To illustrate, only 85 individuals met the criterion in the cube assembly task of Study 1 compared with 211 in the analogies task of Study 1, and across the four tasks in the two studies an average of only 19% of the adults in their 20s were excluded, but an average of 56% of those in their 70s were excluded.

Despite the differential deletion of subjects across decades, the relations between age and perceptual speed and between age and working memory were very similar in each subsample. For example, the correlations in the total sample in Study 1 were −.71 between age and perceptual speed and −.50 between age and working memory, and the range of correlations in the four subsamples was −.67 to −.76 for the age–speed correlation and −.46 to −.59 for the age–working memory correlation. Corresponding values in Study 2 were −.60 for the correlation between age and perceptual speed in the total sample, with a range of −.51 to −.62 in the four subsamples, and −.46 for the total sample correlation between age and working memory, with a range across subsamples of −.32 to −.49. The similarity of these values, as well as the fact that the standard deviations for age in the subsamples were nearly the same as that in the total sample, with means within 7 years of the mean age of the total sample, suggests that the subsamples were comparable to the total samples in at least several important respects.

Mean accuracy for the three complexity levels in each task of the subjects meeting the criterion just described are illustrated in Figure 5 for Study 1, and in Figure 6 for Study 2. Notice that the average level of accuracy is generally lower, and the age trends more negative, as complexity increases from Level 1 to Level 2 to Level 3. The major exceptions in both studies are the most complex version of the paper-folding task, in which the average accuracy was nearly identical to that in the intermediate level of task complexity and did not vary systematically with advancing age. Another exception is evident in the most complex version of the reasoning task in Study 2, in which accuracy was near chance by the decade of the 40s.

Correlations between age and accuracy at each complexity level are presented in Table 3. Note that the correlations increase monotonically with task complexity in five of the eight task-by-study comparisons. The only exceptions are the cases noted earlier; that is, paper-folding measures at Complexity Level 3 in both studies, and the reasoning measure at Complexity Level 3 in Study 2.

Results from the hierarchical regression analyses are summarized in Table 4. Entries in this table indicate the proportion of variance (i.e., the increment in R^2) associated with the specified variable after all of the other variables have been entered into the regression equation. The values therefore correspond to the unique variance associated with each variable, independent of that associated with other variables. The most interesting results in Table 4 are that working memory appears to have a substantial influence on performance at either the intermediate (Level 2) or complex (Level 3) versions of each task but that neither age nor speed has a consistent influence. It also appears that performance at the intermediate level of complexity is primarily affected by variations in working memory, whereas performance at the most complex level is affected both by working memory and by performance at the intermediate level of complexity. This latter pattern is evident in the fact that working memory was involved in five of the six significant predictors of Level 2 accuracy, but it was a significant predictor of Level 3 accuracy in only two contrasts, with Level 2 performance a significant predictor of Level 3 accuracy in three contrasts.

The path analysis model representing the relations among age, speed, working memory, and the three levels of task complexity is illustrated in Figure 7. To improve clarity, the figure portrays the paths from the three causal sources separately, rather than superimposed in the same diagram. However, it should be emphasized that the contributions of age, speed, working memory, and performance at the lowest level of complexity were evaluated simultaneously. That is, coefficients for the nine paths portrayed in this figure, as well as the six por-

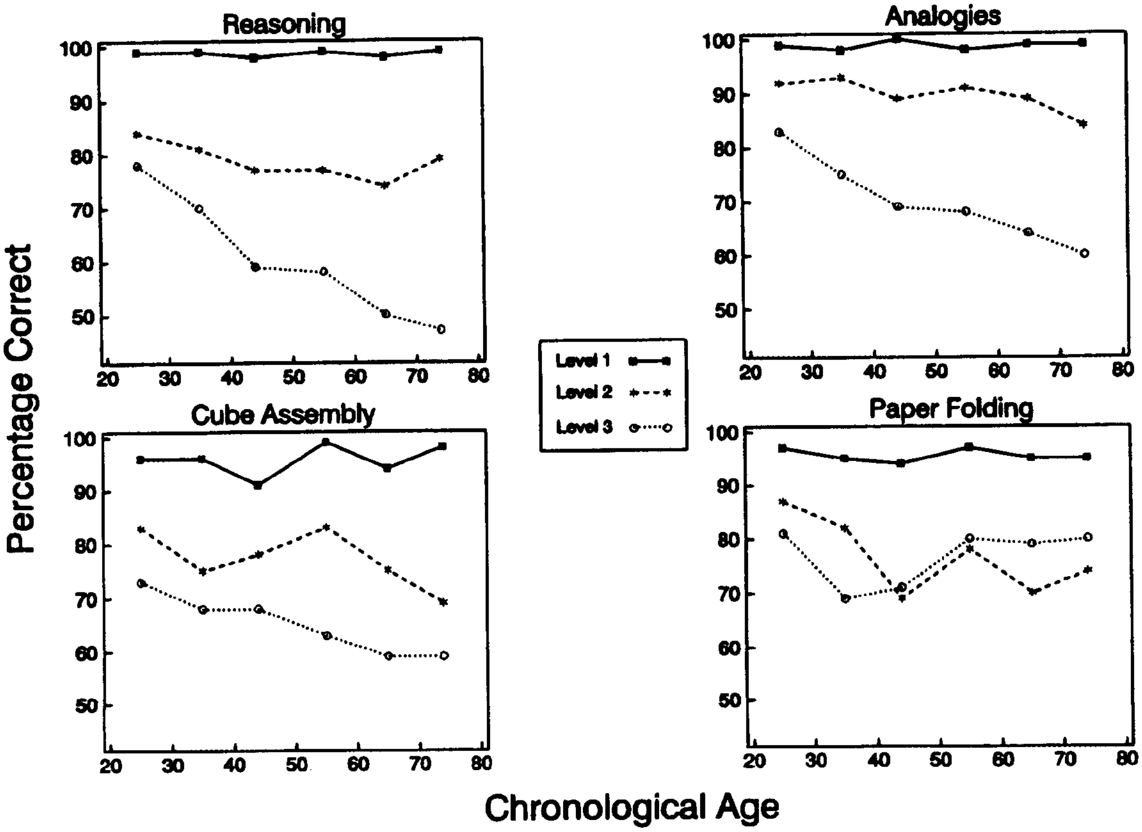

Figure 5. Mean accuracy at the three levels of complexity for the four cognitive tasks in Study 1.