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Meta-Analyses of Age–Cognition Relations in Adulthood: Estimates of Linear and Nonlinear Age Effects and Structural Models

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A meta-analysis was conducted on 91 studies to derive a correlation matrix for adult age, speed of processing, primary–working memory, episodic memory, reasoning, and spatial ability. Structural equation modeling with a single latent common cognitive factor showed that all cognitive measures shared substantial portions of age-related variance. A mediational model revealed that speed of processing and primary–working memory appear to be important mediators of age-related differences in the other measures. However, not all of the age-related influences were mediated. An examination of quadratic age effects and correlational patterns for subsamples under and over 50 years of age revealed that (a) negative age–cognition relations were significant for the 18- to 50-year-old sample and (b) the age-related decline accelerated significantly over the adult life span for variables assessing speed, reasoning, and episodic memory.

Negative relations between age and performance on tests for aspects of fluid cognition (e.g., reasoning, spatial ability, or episodic memory) are well documented (for overviews, see, e.g., Kausler, 1994; Lindenberger & Baltes, 1994; Salthouse, 1991c; and Schaie, 1995). Furthermore, meta-analysis has shown that this age-related decline is moderately large. Performance of older adults was found to be about 1.5 *SD* lower than that of young adults on reasoning tests (Salthouse, 1992c), 1.2 *SD* lower on spatial tests (Salthouse, 1992c), and between 0.7 and 1.0 *SD* (depending on the task) lower for episodic memory performance (Verhaeghen, Marcoen, & Goossens, 1993).

There is growing evidence that adult age differences in fluid aspects of cognition are largely quantitative in nature. For instance, meta-analytic evidence has been accumulated to show that group means of reaction time performance of older adults on a large variety of tasks can be reliably predicted and to a large extent (with R^2s typically larger than .90) from group means of reaction time performance of young adults, without any reference to the specific processes involved (for an overview, see Cerella, 1990; and Myerson & Hale, 1993). Likewise, a meta-analysis on 91 studies demonstrated that group means of proportion of items recalled in episodic memory tasks by older adults can be predicted quite well (R^2 = .83) from the corresponding mean proportion recalled by young adults (Verhaeghen & Marcoen, 1993), again without any reference to the specificities of the memory tasks involved. Such evidence is clearly consistent with the view that age-related changes in the cognitive system are associated with a decline in some general and fundamental mechanism.

One class of models recently advanced for dealing with this general effect in cognitive aging is based on a proposal by Kliegl and Mayr (1992) and can be viewed as a test of the possibility that all of the age-related influences on a wide range of cognitive variables are shared. That is, in these models, a single common factor is postulated to be involved in the mediation of the age-related influences on all cognitive variables. Variants of the model can also be proposed, in which direct relations from age to individual cognitive variables are allowed if the path coefficients are significantly different from zero. Although single common factor models may seem overly simplistic, they have been found to provide moderately good fits to the data in several recent projects (e.g., Lindenberger, Mayr, & Kliegl, 1993; Salthouse, 1996a, 1996b; Salthouse, Hancock, Meinz, & Hambrick, 1996).

An intriguing implication of the single common factor model is that the same determinant may cause age-related declines in a variety of different cognitive variables (Baltes & Lindenberger, 1997; Lindenberger & Baltes, 1994). Because the magnitude of the relations can vary between the common factor and the individual variables and between age and the individual variables, the common factor model does not imply that all variables should exhibit equivalent age-related differences. However, it does suggest that the age-related influences that occur on one variable are likely to have substantial overlap with the age-related influences on other variables.

Another class of models postulates that a limited number of cognitive "primitives" may function as mediators of the age-

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related influences on other cognitive variables. In these models, it is claimed that performance in tasks of episodic memory and fluid cognition is limited by relatively general processing constraints. According to this view, an important factor contributing to age-related cognitive differences is the efficiency or effectiveness of information processing, which pervades almost all aspects and types of processing, thus bringing about a broad decline in many facets of cognitive functioning. In the words of Salthouse, Kausler, and Saults (1988b), this perspective assumes that

> age differences in certain cognitive tasks are not due to impairments in task-specific components or strategies, but instead are at least partially attributable to an age-related reduction in the quantity of some type of general-purpose processing resources considered necessary for efficient functioning in a broad assortment of cognitive tasks. (p. 158)

Much research over the past few decades has been aimed at identifying age differences in such general factors and the implications of these differences for different aspects of cognition.

Two primary types of general factors have been advanced to explain adult age differences in complex cognition. The first type refers to a basic and relatively pervasive loss in processing speed (Cerella, 1990; Myerson, Hale, Wagstaff, Poon, & Smith, 1990; Salthouse, 1985, 1996b).[1] The second possible source of age differences that has been postulated refers to the ability to preserve information in a temporary short-term store while processing is carried out, that is, working memory (Baddeley, 1986; Just & Carpenter, 1992). Both mechanisms seem to fare quite well to account for adult age differences in measures of cognitive functioning. Summarizing 55 comparisons from seven different studies, Salthouse (1993) found that perceptual speed measures were on the average associated with 74% of the age-related variance in different aspects of fluid cognition. The proportion of age-related variance associated with working memory appears to be somewhat smaller but still substantial (around 50%; Salthouse, 1992b). The two mechanisms do not seem to be totally independent because the proportion of age-related variance in cognitive performance that is related to working memory capacity is also shared to a large extent with processing-speed measures (Hultsch, Hertzog, & Dixon, 1990; Park et al., 1996; Salthouse, 1991b, 1992a, 1996b; Salthouse & Meinz, 1995). The implication of this pattern of results seems to be that slowing is a major source of age-related differences in working memory and that both slowing and the concomitant decline in working memory capacities interfere with efficient mnemonic and intellectual functioning in old age.

A moderately large number of structural (i.e., path analysis) models examining the mediational effects of speed, working memory, or both have now been published, with most of them reporting moderate to excellent fits with measures of working memory or processing speed as mediators of the age-related effects on measures of episodic memory, reasoning, and spatial abilities (e.g., Bors & Forin, 1995; Graf & Uttl, 1995; Lindenberger et al., 1993; Park et al., 1996; Salthouse, 1991b, 1992a, 1992b, 1993, 1994b; Salthouse & Babcock, 1991). Mediational models of this type are valuable because they provide information about the relative contributions of different classes of variables as potential mediators of the relations between age and other cognitive variables. The models are based on cross-sectional data, thus strong conclusions about causal ordering among the variables are not justified. Nevertheless, mediational models are relevant to many theoretical hypotheses because the claim that a construct contributes to the age-related effects on other variables is not plausible if the results from mediational analyses are not consistent with the expected relations.

In this meta-analysis, we examine interrelations among age and various measures of cognitive performance, using data from samples composed of a continuous age distribution between about 18 and 80 years. More specifically, we wish to examine the age–cognition relations in terms of both classes of models discussed above: (a) the common factor model and (b) the model positing the mediational role of speed and working memory between age and other aspects of fluid cognition. To obtain a reasonably large sample of correlations, we assigned the dependent variables in individual studies to one of five primary categories: speed, primary–working memory,[2] episodic memory, reasoning, and spatial abilities. Variables that could not be assigned to one of these categories were not included in the analyses. Speed variables consisted largely of measures of reaction time or paper-and-pencil tests of perceptual speed,[3] and

[1] Cerella and Myerson et al. concentrated on performance measured in units of time, whereas Salthouse (1985, 1996b) has emphasized and investigated consequences of age-related slowing in a broader range of variables; but the perspectives are similar with respect to the assumption that age-related slowing is not exclusively a task-specific phenomenon.

[2] We decided to combine measures of primary and working memory into one category to maximize the number of studies for calculating the correlations between these measures and the other cognitive variables. We considered short-term memory measures to be *primary* memory measures if the to-be-remembered items had to be recalled without any modification in order or content; other short-term memory measures were labeled as *working* memory measures. Eleven studies reported correlations for working memory measures and not primary memory measures; in another 11 studies, primary but not working memory measures were used. The mean weighted correlation with age was −.36 (lower limits/upper limits [LL/UL] of the 95% confidence interval (CI): −.39/−.32; Q_T = 24.88, indicating heterogeneity) for working memory and −.19 (LL/UL = −.23/−.15; Q_T = 20.09, indicating heterogeneity) for primary memory; the difference between the two correlations was significant (Q_B = 32.24). Although this result suggests that the age relations were greater with the working memory measures than with the primary memory measures, the most directly relevant information concerns the correlation between the two types of measures. Only two studies (both reported in Salthouse & Babcock, 1991) reported both primary and working memory measures to allow computations of within-construct and between-construct correlations. Over these two studies, the weighted average correlation between the two primary memory and two working memory measures (r = .53) was not much smaller than that between primary memory measures (r = .54) or between working memory measures (r = .59); the between-construct correlations fell within the 95% CI of the within-construct correlation (.46–.59). Largely on the basis of this result, we decided to combine the two types of measures.

[3] Measures for reaction time performance and perceptual speed were combined into one speed category to keep the number of studies for calculating the correlations between these measures and the other cognitive variables sufficiently large. Eight studies reported correlations for reaction time measures and not perceptual speed; in 20 studies, perceptual speed and not reaction time was measured. The mean weighted correlation with age was −.50 (LL/UL = −.53/−.46; Q_T = 35.00,

variables reflecting working memory and primary memory consisted of measures representing the number of items that could be remembered immediately either with (working memory) or without (primary memory) additional processing requirements. Measures of episodic memory were derived from a variety of free recall, list learning, and paired associates tests. Measures of reasoning and spatial abilities were obtained from a mixture of psychometric tests (e.g., Raven [1960] Progressive Matrices and Shipley [1940] Abstraction for reasoning; Surface Development and Paper Folding [Salthouse & Mitchell, 1990] for spatial ability) and experimental tasks requiring abstraction and induction (reasoning) or integration and transformation (spatial) operations. The correlations found in those studies were pooled using the system advocated by Hedges and Olkin (1985) to yield a "best estimate" matrix of the interrelations among age and the five cognitive variables of interest. This meta-analytically derived correlation matrix was then used to examine the plausibility of the two models mentioned above by applying structural equation modeling (Shadish, 1996).

Because the original data were available from the studies conducted by Salthouse and colleagues, we took this opportunity to examine possible nonlinear effects of aging in these data. In the literature, many positions have been advanced regarding the pattern of (cross-sectional) decline in fluid cognition: linear (e.g., Wechsler, 1958), accelerating (e.g., Rabbitt & Abson, 1990), inverted-U-shaped (Rabbitt, 1990), abruptly changing (e.g., Talland, 1968), and even decelerating patterns (e.g., Orme, 1957) have all been mentioned. Recent years have brought no consensus (see Salthouse, 1991c, for an overview). Our meta-analysis on a large corpus of data may shed more light on this matter.

Furthermore, to determine whether the magnitude or pattern of the relations among variables differed across young and older adulthood, we created two subsamples: one consisting of participants between 18 and 50 years of age, the other consisting of participants 51 years old and older. Standard two-group structural equation modeling analyses were then used to examine relations among age and the available measures of cognitive functioning in the two groups.

To summarize, the primary purposes of this project were (a) to conduct a meta-analysis of the interrelations among age and various measures of cognitive functioning, (b) to use these meta-analytically derived correlations as the basis for investigating alternative structural models of the relations between age and cognition, and (c) to examine whether the impact of age on cognition, the relations among cognitive variables, or both varied across the periods of younger and older adulthood.

indicating heterogeneity) for reaction time, −.54 (LL/UL = −.55/−.52; Q_T = 170.36, indicating heterogeneity) for perceptual speed; the difference between the two correlations was significant (Q_B = 4.38). Moreover, when we compared correlations among measures of perceptual speed (digit–symbol reaction time, letter comparison speed and pattern comparison speed) with their correlation to a choice reaction time measure (digit–digit reaction time) in 12 studies by Salthouse and colleagues included in our sample, the former correlation was larger (.61; LL/UL = .58/.64) than the latter (.56; LL/UL = .53/.59). Although this suggests that reaction time and perceptual speed are probably distinct constructs (also see Earles & Salthouse, 1995), they seem sufficiently highly related to make it meaningful to treat them together in our analysis. Converging evidence for this position can be found in a study on a large sample of speed measures (Salthouse, 1996a) where it was found that although method factors could be distinguished within measures of processing speed, correlations among factors was quite high (viz., .77 between reaction time and paper-and-pencil speed).

Method

A literature search was conducted for studies that (a) included a participant sample of normal (i.e., free from known psychological or organic pathology as indicated by a self-report) adults sampled over the whole age range included in the study, with the youngest participant 30 years of age or younger and the oldest, 60 years of age or older; (b) assessed performance on at least one measure of the five target cognitive variables (speed, primary–working memory, episodic memory, reasoning, and spatial ability); and (c) reported correlation coefficients among (at least some of) the variables of interest. Sample size was not a criterion, but the smallest sample in our set was 35, and most studies had 100 participants or more. An automated search of CD-ROM databases to find such studies was not considered appropriate because we were looking for a particular way of reporting the data (i.e., in the form of a correlation matrix). Therefore, it was decided that we would manually search articles published in the major journals concerned with aging (i.e., *Experimental Aging Research, Journal of Gerontology: Psychological Sciences,* and *Psychology and Aging*) over the past 20 years (ending in April 1996). In addition, miscellaneous articles and monographs cited in those sources or known to us were examined. Also, all relevant prior research projects conducted by Timothy A. Salthouse were included. Because it is difficult to determine a priori which sources might contain relevant correlation matrices, we cannot claim that the search process was exhaustive. Although relevant articles may have been inadvertently omitted, we are not aware of any systematic biases in the data sets that were included, thus we have no reason to believe that the results are not representative of the contemporary literature. All participant samples were independent from each other (i.e., to the best of our knowledge, no participant contributed data to more than one study[4]). No studies were excluded from the analyses for reasons other than not satisfying the above-mentioned inclusion criteria.

A total of 75 relevant research articles were retrieved (as indicated with an asterisk in the References section). In these articles, a total of 91 studies was reported. For the nonlinearity analysis and the meta-analysis on separate age groups, only studies from the Salthouse laboratory were included because these analyses required data that were not available in published articles based on other data sets.

We classified the tests and tasks used in the primary studies by mutual agreement. Tasks classified as yielding speed measures included simple reaction time, choice reaction time, and a variety of perceptual speed measures (e.g., tasks requiring matching, search, and substitution). Tasks categorized as yielding primary–working memory measures included forward or backward verbal or spatial span and working memory tasks, such as reading or computation span. Episodic memory measures were derived from free recall tasks, paired-associate recall tasks, and prose recall tasks. Reasoning measures were obtained from matrices, series completions, analogies, figural relations, and category tests or experimental tasks. Finally, spatial ability measures were derived from psychometric tests and experimental tasks of closure, cube assembly, surface development, paper folding, block design, and integration–synthesis.

[4] One exception is the article by Mason and Ganzler (1964), which contains three partially overlapping samples.

Statistical Analysis

Correlation coefficients between pairs of the six variables (i.e., age and the five cognitive variables) were aggregated over studies by using the procedure advocated by Hedges and Olkin (1985). In a number of cases, more than one measure for each construct was included within a single study. To avoid stochastic dependence among combined correlations, we averaged correlations between measures representing the same pairs of constructs within the same study to yield a single estimate of each relevant correlation per study. The averaging of the correlations consisted of first transforming the relevant correlations to Fisher z scores, averaging those, and then converting the average Fisher z value back to a single correlation coefficient. Correlation coefficients for each study can be found in Table 1, along with the number of participants and the number of correlations contributing to the average correlation.

In our meta-analysis, the mean weighted correlation coefficient (r_+) for each pair of variables was computed according to the formulas by Hedges and Olkin (1985), in which differential weight is given to each correlation coefficient as a function of sample size. CIs can be established around r_+, allowing a test of whether the mean weighted correlation differed significantly from either zero or unity. An additional statistic, Q_T, allows one to test whether these coefficients are homogeneous; that is, whether the variation around the mean weighted correlation is small enough to make r_+ a true point estimate of a single population correlation. If this Q_T statistic, which is chi-square distributed with $k - 1$ df (degree of freedom, where k corresponds to the number of studies from which r_+ is calculated), exceeds the critical value, r_+ is nonhomogeneous. Q_B is a statistic used to test for between-group homogeneity, that is, testing for whether two mean weighted correlations based on independent samples are different. This statistic is chi-square distributed with $p - 1$ df, where p corresponds to the number of comparisons.

The resulting 6×6 r_+ matrix was submitted to linear structural modeling with the LISREL 8 program (Jöreskog & Sörbom, 1993) to obtain path coefficients and tests of model fit. The number of participants used for the computation of the LISREL chi-square statistic was the average number of participants on which the r_+s in the matrix were based. This choice of N (rather than using the average of the average N per study) is in line with both the logic of meta-analysis as a data-pooling enterprise (Bangert-Drowns, 1986) and the one previous study subjecting meta-analytically derived correlations to linear structural analysis that we were able to locate (Premack & Hunter, 1988). LISREL offers a number of fit statistics. Chi-square is an index of the mis-specification of the model as compared with the original matrix; higher values indicate bad fit. This statistic can also be used to compare models that stand in a nested, or hierarchical, relationship. That is, if a model can be obtained from another model by fixing one or more variables, the difference in the chi-square statistic values between the models provides a chi-square test for the significance of the difference between the models, with the difference in the dfs of the two models as the dfs for the test. Note that if N is large, this difference in chi-square statistics may well be significant, even if other fit statistics do not change much. Chi-square, however, is dependent on sample size, with larger samples leading to higher values of this statistic and thus to easy rejection of the model. A number of other fit indices are much less dependent on sample size and hence were also examined in evaluating the models. The goodness of fit index (GFI) and the normed fit index (NFI) evaluate fit on a scale that runs from 0 (*no fit*) to 1 (*perfect fit*); GFI measures the correspondence between the observed and the estimated matrix, and NFI is basically a rescaling of the chi-square statistic on a scale from 0 to 1. The adjusted goodness of fit (AGFI; only available for single group analyses) is equal to the GFI but takes the number of dfs into account and thus gives an indication of the parsimony of the model. The (standardized) root mean square residual (RMR) is the square root of the mean of the square discrepancies between the observed and the estimated matrices; better fit with this measure is represented by values closer to zero. A comparative overview of these and other fit indices can be found in Bollen (1989) and Loehlin (1987). Ideally, a covariance matrix should be used for linear structural modeling. This was impossible in our meta-analysis. However, the models estimated are scale invariant, implying that parameter estimates and goodness-of-fit tests (and consequently also difference tests for nested models) are correct even though problems may arise with estimates of standard errors of individual parameters (Cudeck, 1989).

Results

Total Sample of Studies

Mean weighted correlations. Mean weighted correlations for the total sample, along with the 95% CI and the homogeneity statistic, are reported in Table 2. As can be seen by the CIs, all of the correlations were significantly different from zero and unity. The results indicate that the largest age relations are evident on the measures of speed ($r_+ = -.52$), with relations between age and measures of reasoning ($r_+ = -.40$) and between age and measures of spatial ability ($r_+ = -.38$) next largest, followed by somewhat smaller but still moderate relations between age and episodic memory ($r_+ = -.33$) and age and primary–working memory ($r_+ = -.27$). The relations between the cognitive variables were all moderate in magnitude, with the weighted correlations ranging from .27 to .55.

Moderator and disjoint cluster analysis. The weighted correlation estimates in Table 2 were all nonhomogeneous, indicating considerable variability around the mean weighted average. Several attempts were made to identify moderators of the age–cognition relations by breaking down the average weighted correlation by type of measure. None of these efforts resulted in the desired combination of within-type homogeneity and between-type heterogeneity. First, speed was decomposed into paper-and-pencil and reaction time measures. As reported in Footnote 3, this resulted in two significantly different but still nonhomogeneous classes of age–speed correlations. Second, primary–working memory was broken down into primary memory measures and working memory measures. As reported in Footnote 2, the resulting age–primary/working memory correlation classes were significantly different from each other but were not homogeneous. Third, the age–reasoning correlations were decomposed into four types of tests: Raven Progressive Matrices ($k = 8$, $r_+ = -.49$, 95% CI = ranging from $-.53$ to

−.45; Q_T = 70.63, indicating heterogeneity), Shipley Abstraction (k = 3, r_+ = −.37; LL/UL of the 95% CI = −.43/−.30; Q_T = 4.14, indicating homogeneity), Primary Mental Abilities Test (Thurstone, 1938) Reasoning subtest (k = 3, r_+ = −.49, LL/UL = −.39/−.29; Q_T = 3.58, indicating homogeneity); and the Category Test (Halstead, 1947; k = 3, r_+ = −.44, LL/UL = −.51/−.35; Q_T = 4.09, indicating homogeneity). The between-classes homogeneity statistic was significant (Q_B = 24.13), showing that the correlations differ across types of variables; the CIs show that the age effect is larger on the Raven test than on the other reasoning measures. However, the number of studies within the homogeneous samples was considered too small to justify as input for a meta-analysis. Fourth, there proved to be no between-classes heterogeneity (Q_B = 6.35) in the age–space correlations when these were divided according to type of measure: spatial subtests of the Wechsler Adult Intelligence Scale (k = 6, r_+ = −.37, LL/UL = −.39/−.34; Q_T = 8.87, indicating homogeneity), Hooper Visual Organization Test (k = 5, r_+ = −.43, LL/UL = −.49/−.37; Q_T = 3.19, indicating homogeneity), Embedded Figures Test (k = 4, r_+ = −.31, LL/UL = −.39/−.23; Q_T = 4.49, indicating homogeneity), and various rotation tests (k = 3, r_+ = −.36, LL/UL = −.43/−.29; Q_T = 4.69, indicating homogeneity). Again, the sample of studies within each homogeneous class is quite small.

Because a large number of the studies included in our sample originated from the same laboratory (viz., Timothy A. Salthouse's laboratory at the Georgia Institute of Technology), we examined whether the age relations in these studies differed from those in studies reported by other investigators. It was found that the age–speed relation was smaller in the Salthouse data as compared with the rest of the data (Salthouse k = 28, r_+ = −.50, LL/UL = −.52/−.48, Q_T = 90.83, indicating heterogeneity; other data: k = 22, r_+ = −.53, LL/UL = −.55/−.51, Q_T = 150.86, indicating heterogeneity; Q_B = 6.13, indicating a significant difference between the two classes), as was the age–reasoning relation (Salthouse: k = 10, r_+ = −.36, LL/UL = −.40/−.33, Q_T = 45.27, indicating heterogeneity; other data: k = 28, r_+ = −.42, LL/UL = −.44/−.40, Q_T = 121.10, indicating heterogeneity; Q_B = 13.98, indicating a significant difference between the two classes). The age–primary/working memory relation was larger in the Salthouse data than in the rest of the data (Salthouse: k = 14, r_+ = −.33, LL/UL = −.36/−.29, Q_T = 47.02, indicating heterogeneity; other data: k = 20, r_+ = −.23, LL/UL = −.26/−.20, Q_T = 54.02, indicating heterogeneity; Q_B = 18.33, indicating a significant difference between the two classes). No differences between the two groupings were found for the age–episodic memory relation (Salthouse: k = 14, r_+ = −.33, LL/UL = −.36/−.30, Q_T = 27.51, indicating heterogeneity; other data: k = 15, r_+ = −.34, LL/UL = −.37/−.31, Q_T = 61.83, indicating heterogeneity; Q_B = 0.14, indicating no significant difference between the two classes) and the age–space relation (Salthouse: k = 12, r_+ = −.36, LL/UL = −.39/−.32, Q_T = 32.73, indicating heterogeneity; other data: k = 24, r_+ = −.39, LL/UL = −.40/−.37, Q_T = 69.22, indicating heterogeneity; Q_B = 2.54, indicating no significant difference between the two classes). None of the groupings proved homogeneous.

Finally, we decided to tackle the problem of heterogeneity in the data by removing outlying clusters after a disjoint cluster analysis, as advocated by Hedges and Olkin (1985). In this analysis, the correlation coefficients from the individual studies are ordered as a function of magnitude, and statistics are applied to test whether the gaps between two adjacent correlations are large enough to conclude that these correlations are significantly different. In this way, the data are split into disjoint clusters at each of the gaps. We decided to keep the largest cluster in our analysis and to discard the correlations contained in the other clusters (if any) as outliers. Disjoint clusters were found for the following correlations: age–reasoning (five studies in one disjoint cluster, one study in another), speed–primary/working memory (two studies in one disjoint cluster, one in another), speed–episodic memory (two studies in one disjoint cluster), speed–reasoning (two studies in one disjoint cluster, two in another), episodic memory–reasoning (one study in one disjoint cluster, two in another), and reasoning–space (one study in one disjoint cluster). The mean weighted correlations after we discarded the disjoint clusters, the number of studies they are based on, and relevant statistics can be found in Table 2. It can be seen that the homogeneity in the largest joint cluster was always considerably smaller than in the original data; in three cases, the homogeneity statistic became nonsignificant. With the exception of the speed–reasoning relation, discarding of disjoint clusters did not greatly alter the estimates of the relations (the largest change from this procedure was .03, with the exception of the speed–reasoning relation that changed by .09). All structural equation models were computed using the matrix of correlations as derived from the disjoint cluster analysis.

Reliability of the cognitive measures. It is possible that differential correlations between age and cognition and among cognitive variables are at least in part influenced by (un)reliability of the measures. To explore this possibility, we computed split-half reliability coefficients from the Salthouse data using the Spearman–Brown formula wherever possible. Mean weighted reliabilities for the five cognitive variables are presented in Table 3 (reliability was also estimated separately for two age groups, see below). From this table, it can be concluded that reliability proved satisfactory for all measures,[5] with measures of episodic memory appearing as the least reliable and measures of speed and spatial ability as the most reliable.

Structural equation modeling: The common factor model. In the first model fitted to the correlation matrix, all cognitive variables load on a single common factor. Two steps were taken in estimating this model. First, paths were determined from age to the common factor and from the common factor to the cognitive variables. The resulting path coefficients are represented in Figure 1 as solid lines. The chi-square statistic for this model was quite high, indicating unsatisfactory fit, $\chi^2(8, N = 4{,}809) = 498.49, p < .001$. However, chi-square statistics for structural models are based on the number of participants, with larger numbers leading to higher power in the test and thus to an easy rejection of the model. Given the large number of participants in the meta-analytically derived estimates, fit indices not based on sample size seem a better choice, and model fit evaluated

[5] All structural equation models were re-estimated using the matrix of disattenuated correlations; the results were very similar to those obtained using the original data.

Table 1
Correlations From Individual Studies in the Meta-Analysis

Study	N	Age range (in years)	j	r
Age–speed				
Aftanas & Royce (1969)	100	16–70	2	−.33
Baltes & Lindenberger (1997)	171	25–69	1	−.49
Birren & Morrison (1961)	933	25–64	1	−.46
Bors & Forrin (1995)	63	26–80	1	−.40
Botwinick & Storandt (1974)	120	20–80	3	−.57
Bunce et al. (1996)	90	18–62	1	−.54
Bunce et al. (1993)	116	17–63	1	−.46
Clark (1960)	102	20–70	2	−.49
Cohn et al. (1984)	80	21–90	2	−.30
Crook & West (1990)	1,205	18–90	1	−.57
Dirken (1972)	316	30–69	2	−.38
Fastenau et al. (1996)	90	30–80	4	−.46
Goldfarb (1941, men)	108	18–64	4	−.38
Goldfarb (1941, women)	60	18–64	4	−.27
Graf & Uttl (1995)	163	16–84	1	−.36
Horn et al. (1981, Study 2)	105	20–60	1	−.41
Horn et al. (1981, Study 3)	147	20–60	1	−.23
Koss et al. (1991)	67	21–92	1	−.71
Meinz & Salthouse (in press)	128	18–83	4	−.47
Park et al. (1996)	301	20–90	3	−.64
Robertson-Tchabo & Arenberg (1976)	96	20–80	5	−.38
Salthouse (1991a)	132	21–80	2	−.52
Salthouse (1991b, Study 1)	221	20–80	2	−.57
Salthouse (1991b, Study 2)	228	20–82	2	−.67
Salthouse (1991b, Study 3)	223	20–84	2	−.57
Salthouse (1992a)	100	18–80	3	−.59
Salthouse (1993)	305	19–84	6	−.45
Salthouse (1994a, Study 1)	240	19–82	6	−.47
Salthouse (1994a, Study 2)	125	20–89	6	−.45
Salthouse (1994b, Study 1)	246	18–84	3	−.58
Salthouse (1994b, Study 2)	258	20–87	4	−.45
Salthouse (1995a)	173	18–88	4	−.52
Salthouse (1995b)	117	20–79	5	−.53
Salthouse (1996a)	172	18–93	9	−.65
Salthouse & Babcock (1991, Study 2)	233	18–82	3	−.55
Salthouse et al. (1995)	131	17–79	4	−.60
Salthouse, Fristoe, et al. (1996)	259	18–94	5	−.54
Salthouse, Hambrick, et al. (1996)	77	18–80	4	−.47
Salthouse & Hancock (1995, Study 1)	137	18–78	4	−.40
Salthouse & Hancock (1995, Study 2)	58	18–61	4	−.33
Salthouse, Hancock, et al. (1996)	197	18–92	4	−.46
Salthouse et al. (1988a, Study 1)	127	20–79	2	−.52
Salthouse et al. (1988a, Study 2)	233	20–78	2	−.39
Salthouse et al. (1994, Study 1)	165	20–67	2	−.40
Salthouse et al. (1994, Study 2)	223	18–70	2	−.48
Salthouse et al. (1994, Study 3)	239	30–75	1	−.49
Salthouse & Meinz (1995)	242	18–89	5	−.54
Salthouse & Mitchell (1990)	383	18–84	2	−.24
Schaie (1989, Study 1)	611	25–81	1	−.68
Schaie (1989, Study 2)	628	25–81	1	−.65
Age–primary/working memory				
Albert et al. (1988)	80	30–80	1	−.16
Birren & Morrison (1961)	933	25–64	1	−.19
Botwinick & Storandt (1974)	120	20–80	4	−.31
Dirken (1972)	316	30–69	1	−.10
Fastenau et al. (1996)	90	30–80	2	−.38
Goldfarb (1941, men)	108	18–64	1	−.18
Goldfarb (1941, women)	60	18–64	1	−.06
Heron & Chown (1967, men)	300	20–79	2	−.25
Heron & Chown (1967, women)	240	20–79	2	−.16
Hooper et al. (1984)	180	17–80	3	−.21
Horn et al. (1981, Study 1)	240	20–60	2	−.20
Age–primary/working memory (*continued*)				
Horn et al. (1981, Study 2)	105	20–60	2	−.14
Horn et al. (1981, Study 3)	147	20–60	2	−.14
Kirasic et al. (1996)	477	17–87	2	−.37
Koss et al. (1991)	67	21–92	1	−.09
Park et al. (1996)	301	20–90	3	−.31
Perlmutter & Nyquist (1990)	127	20–90	1	.03
Robertson-Tchabo & Arenberg (1976)	96	20–80	2	−.33
Salthouse (1991b, Study 1)	221	20–80	2	−.48
Salthouse (1991b, Study 2)	228	20–82	2	−.46
Salthouse (1991b, Study 3)	223	20–84	2	−.41
Salthouse (1992a)	100	18–80	2	−.34
Salthouse (1995b)	117	20–79	2	−.31
Salthouse & Babcock (1991, Study 1)	227	20–87	4	−.44
Salthouse & Babcock (1991, Study 2)	233	18–82	4	−.33
Salthouse et al. (1995)	131	17–79	1	−.36
Salthouse & Hancock (1995, Study 1)	137	18–78	1	−.25
Salthouse, Hancock, et al. (1996)	197	18–92	3	−.26
Salthouse et al. (1994, Study 1)	165	20–67	2	−.19
Salthouse et al. (1994, Study 3)	239	30–75	2	−.11
Salthouse & Meinz (1995)	242	18–89	2	−.16
Salthouse et al. (1989)	120	20–78	1	−.46
Stankov (1988)	100	20–70	1	−.33
Stankov (1994)	164	19–89	2	−.46
Age–episodic memory				
Aftanas & Royce (1969)	100	16–70	2	.10
Albert et al. (1988)	80	30–80	2	−.28
Baltes & Lindenberger (1997)	171	25–69	1	−.30
Bors & Forrin (1995)	63	26–80	1	−.26
Botwinick & Storandt (1974)	120	20–80	5	−.49
Clark (1960)	102	20–70	1	−.40
Crook & West (1990)	1,205	18–90	3	−.41
Fastenau et al. (1996)	90	30–80	2	−.38
Graf & Uttl (1995)	163	16–84	1	−.52
Horn et al. (1981, Study 1)	240	20–60	1	−.13
Horn et al. (1981, Study 2)	105	20–60	4	−.19
Horn et al. (1981, Study 3)	147	20–60	2	−.15
Koss et al. (1991)	67	21–92	3	−.29
Meinz & Salthouse (in press)	128	18–83	1	−.32
Park et al. (1996)	301	20–90	4	−.35
Robertson-Tchabo & Arenberg (1976)	96	20–80	2	−.29
Salthouse (1993)	305	19–84	4	−.31
Salthouse (1994a, Study 1)	240	19–82	1	−.31
Salthouse (1994a, Study 2)	125	20–89	1	−.20
Salthouse (1994b, Study 1)	246	18–84	2	−.27
Salthouse (1994b, Study 2)	258	20–87	1	−.27
Salthouse (1995a)	173	18–88	1	−.41
Salthouse (1995b)	117	20–79	1	−.49
Salthouse (1996a)	172	18–93	3	−.32
Salthouse, Fristoe, et al. (1996)	259	18–94	2	−.50
Salthouse, Hancock, et al. (1996)	197	18–92	1	−.33
Salthouse, Kausler, et al. (1988a, Study 1)	129	20–79	2	−.23
Salthouse, Kausler, et al. (1988a, Study 2)	233	20–78	2	−.40
Salthouse et al. (1994, Study 3)	239	30–75	1	−.22
Age–reasoning				
Aftanas & Royce (1969)	100	16–70	2	−.33
Arenberg (1988)	828	20s–80s	1	−.45
Baltes & Lindenberger (1997)	171	25–69	1	−.41
Barr & Giambra (1990)	90	19–71	1	−.50

Table 1 (*continued*)

Study	N	Age range (in years)	j	r
Age–reasoning (*continued*)				
Bors & Forrin (1995)	63	26–80	1	−.28
Bromley (1991)	240	20–86	1	−.62
Burke (1972)	567	26–64	1	−.26
Charness (1987)	45	21–71	1	−.52
Clark (1960)	102	20–70	1	−.49
Cornelius (1984)	100	18–89	3	−.36
Davies & Leytham (1964)	96	20–79	1	−.62
Edwards & Wine (1963)	80	22–76	1	−.55
Heron & Chown (1967, men)	300	20–79	1	−.64
Heron & Chown (1967, women)	240	20–79	1	−.51
Hooper et al. (1984)	180	17–80	3	−.35
Hoyer et al. (1979)	60	18–85	1	−.44
Koss et al. (1991)	67	21–92	1	−.49
Kraus et al. (1967)	200	16–65	1	−.33
Mason & Ganzler (1964, Sample 1)	198	25–75	1	−.29
McCrae et al. (1987)	708	17–101	2	−.44
Pierce et al. (1989)	289	18–72	1	−.40
Prigatano & Parsons (1976)	35	16–61	1	−.42
Salthouse (1991b, Study 1)	221	20–80	2	−.52
Salthouse (1991b, Study 2)	228	20–82	2	−.42
Salthouse (1991b, Study 3)	223	20–84	2	−.45
Salthouse (1993)	305	19–84	3	−.35
Salthouse (1994b, Study 1)	246	18–84	2	−.37
Salthouse (1994b, Study 2)	258	20–87	1	−.09
Salthouse, Fristoe, et al. (1996)	259	18–94	1	−.45
Salthouse et al. (1988a, Study 2)	233	20–78	2	−.36
Salthouse & Mitchell (1990)	383	18–84	2	−.25
Salthouse et al. (1989)	120	20–78	1	−.51
Schaie (1989, Study 1)	611	25–81	1	−.53
Schaie (1989, Study 2)	628	25–81	1	−.18
Schludermann et al. (1983)	558	24–85	1	−.42
Stankov (1994)	164	19–89	1	−.39
Vega & Parsons (1967)	50	?[a]	1	−.63
Wilson (1963)	96	20–79	1	−.62
Age–space				
Aftanas & Royce (1969)	100	16–70	1	−.36
Barrett et al. (1977)	70	25–64	1	−.28
Birren & Morrison (1961)	933	25–64	3	−.36
Botwinick & Storandt (1974)	120	20–80	2	−.50
Chown (1961)	200	20–82	1	−.37
Clark (1960)	102	20–70	1	−.42
Crosson (1984)	160	23–77	1	−.20
Goldfarb (1941, men)	108	18–64	3	−.19
Goldfarb (1941, women)	60	18–64	3	−.21
Heron & Chown (1967, men)	300	20–79	1	−.55
Heron & Chown (1967, women)	240	20–79	1	−.28
Kaufman et al. (1989)	1,480	20–74	3	−.40
Kirasic et al. (1996)	477	17–87	2	−.25
Koss et al. (1991)	67	21–92	3	−.45
Lee & Pollack (1978)	72	20–79	1	−.43
Mason & Ganzler (1964, Sample 2)	193	25–75	1	−.45
Mason & Ganzler (1964, Sample 3)	213	25–75	1	−.38
McArdle & Prescott (1992)	1,680	19–?[b]	3	−.36
Riege & Inman (1981)	120	20–84	1	−.51
Salthouse (1991a)	132	21–80	4	−.25
Salthouse (1991b, Study 2)	228	20–82	2	−.16
Salthouse (1991b, Study 3)	223	20–84	2	−.34
Salthouse (1993)	305	19–84	1	−.39
Salthouse (1994b, Study 1)	246	18–84	2	−.39
Salthouse (1994b, Study 2)	258	20–87	1	−.28
Salthouse (1995b)	117	20–79	1	−.34
Salthouse, Fristoe, et al. (1996)	259	18–94	3	−.46
Age–space (*continued*)				
Salthouse et al. (1988a, Study 1)	129	20–79	2	−.24
Salthouse & Meinz (1995)	242	18–89	1	−.45
Salthouse & Mitchell (1990)	383	18–84	2	−.34
Salthouse et al. (1989)	120	20–78	1	−.57
Schaie (1989, Study 1)	611	25–81	1	−.41
Schaie (1989, Study 2)	628	25–81	1	−.47
Sterne (1973)	75	20–72	1	−.42
Tamkin & Jacobsen (1984)	211	20–79	1	−.50
Wasserstein et al. (1987)	80	20–68	1	−.58
Speed–primary/working memory				
Birren & Morrison (1961)	933	25–64	1	.45
Botwinick & Storandt (1974)	120	20–80	12	.34
Dirken (1972)	316	30–69	2	.12
Fastenau et al. (1996)	90	30–80	8	.44
Goldfarb (1941, men)	108	18–64	4	.29
Goldfarb (1941, women)	60	18–64	4	−.16
Horn et al. (1981, Study 2)	105	20–60	2	.30
Horn et al. (1981, Study 3)	147	20–60	2	.29
Park et al. (1996)	301	20–90	9	.39
Robertson-Tchabo & Arenberg (1976)	96	20–80	10	.11
Salthouse (1991b, Study 1)	221	20–80	4	.49
Salthouse (1991b, Study 2)	228	20–82	4	.51
Salthouse (1991b, Study 3)	223	20–84	4	.53
Salthouse (1992a)	100	18–80	6	.36
Salthouse (1995b)	117	20–79	10	.29
Salthouse & Babcock (1991, Study 2)	233	18–82	12	.42
Salthouse et al. (1995)	131	17–79	5	.37
Salthouse & Hancock (1995, Study 1)	137	18–78	4	.37
Salthouse, Hancock, et al. (1996)	197	18–92	12	.38
Salthouse et al. (1994, Study 1)	165	20–67	4	.25
Salthouse et al. (1994, Study 3)	239	30–75	2	.27
Salthouse & Meinz (1995)	242	18–89	10	.31
Speed–episodic memory				
Aftanas & Royce (1969)	100	16–70	4	.11
Baltes & Lindenberger (1997)	171	25–69	1	.42
Bors & Forrin (1995)	63	26–80	1	.34
Botwinick & Storandt (1974)	120	20–80	15	.32
Clark (1960)	102	20–70	2	.47
Crook & West (1990)	1,205	18–90	3	.31
Fastenau et al. (1996)	90	30–80	8	.35
Graf & Uttl (1995)	163	16–84	1	.39
Horn et al. (1981, Study 2)	105	20–60	4	.40
Horn et al. (1981, Study 3)	147	20–60	2	.38
Meinz & Salthouse (in press)	128	18–83	4	.32
Park et al. (1996)	301	20–90	12	.43
Robertson-Tchabo & Arenberg (1976)	96	20–80	10	.27
Salthouse (1993)	305	19–84	24	.30
Salthouse (1994a, Study 1)	240	19–82	6	.46
Salthouse (1994a, Study 2)	125	20–89	6	.36
Salthouse (1994b, Study 1)	246	18–84	6	.27
Salthouse (1994b, Study 2)	258	20–87	4	.38
Salthouse (1995a)	173	18–88	4	.36
Salthouse (1995b)	117	20–79	5	.39
Salthouse (1996a)	172	18–93	27	.34
Salthouse, Fristoe, et al. (1996)	259	18–94	10	.39
Salthouse, Hancock, et al. (1996)	197	18–92	4	.34
Salthouse et al. (1988a, Study 1)	129	20–79	4	.25
Salthouse et al. (1988a, Study 2)	233	20–78	4	.05
Salthouse et al. (1994, Study 3)	239	30–75	1	.26

(*table continues*)

Table 1 (*continued*)

Study	N	Age range (in years)	j	r
Speed–reasoning				
Aftanas & Royce (1969)	100	16–70	4	.20
Baltes & Lindenberger (1997)	171	25–69	1	.42
Bors & Forrin (1995)	63	26–80	1	.51
Clark (1960)	102	20–70	2	.49
Salthouse (1991b, Study 1)	221	20–80	4	.56
Salthouse (1991b, Study 2)	228	20–82	4	.48
Salthouse (1991b, Study 3)	223	20–84	4	.39
Salthouse (1993)	305	19–84	18	.50
Salthouse (1994b, Study 1)	246	18–84	6	.42
Salthouse (1994b, Study 2)	258	20–87	4	.39
Salthouse, Fristoe, et al. (1996)	259	18–94	5	.54
Salthouse et al. (1988a, Study 2)	233	20–78	4	.25
Salthouse & Mitchell (1990)	383	18–84	2	.40
Schaie (1989, Study 1)	611	25–81	1	.71
Schaie (1989, Study 2)	628	25–81	1	.72
Speed–space				
Aftanas & Royce (1969)	100	16–70	2	.08
Birren & Morrison (1961)	933	25–64	3	.49
Botwinick & Storandt (1974)	120	20–80	6	.38
Clark (1960)	102	20–70	2	.45
Goldfarb (1941, men)	108	18–64	12	.24
Goldfarb (1941, women)	60	18–64	12	.21
Salthouse (1991a)	132	21–80	8	.25
Salthouse (1991b, Study 2)	228	20–82	4	.16
Salthouse (1991b, Study 3)	223	20–84	4	.32
Salthouse (1993)	305	19–84	6	.45
Salthouse (1994b, Study 1)	246	18–84	12	.39
Salthouse (1994b, Study 2)	258	20–87	6	.35
Salthouse (1995b)	117	20–79	10	.38
Salthouse, Fristoe, et al. (1996)	259	18–94	15	.33
Salthouse et al. (1988a, Study 1)	129	20–79	4	.05
Salthouse & Meinz (1995)	242	18–89	5	.50
Salthouse & Mitchell (1990)	383	18–84	4	.27
Schaie (1989, Study 1)	611	25–81	1	.49
Schaie (1989, Study 2)	628	25–81	1	.55
Primary/working memory–episodic memory				
Albert et al. (1988)	80	30–80	2	.55
Botwinick & Storandt (1974)	120	20–80	20	.23
Fastenau et al. (1996)	90	30–80	4	.40
Horn et al. (1981, Study 1)	240	20–60	2	.33
Horn et al. (1981, Study 2)	105	20–60	8	.54
Horn et al. (1981, Study 3)	147	20–60	4	.44
Park et al. (1996)	301	20–90	12	.40
Robertson-Tchabo & Arenberg (1976)	96	20–80	4	.27
Salthouse (1995b)	117	20–79	2	.28
Salthouse, Hancock, et al. (1996)	197	18–92	3	.40
Salthouse et al. (1994, Study 3)	239	30–75	2	.24
Primary/working memory–reasoning				
Heron & Chown (1967, men)	300	20–79	2	.45
Heron & Chown (1967, women)	240	20–79	2	.44
Hooper et al. (1984)	180	17–80	9	.26
Primary/working memory–reasoning (*continued*)				
Salthouse (1991b, Study 1)	228	20–82	4	.34
Salthouse (1991b, Study 2)	223	20–84	4	.47
Salthouse (1991b, Study 3)	221	20–80	4	.59
Salthouse et al. (1989)	120	20–78	1	.48
Stankov (1994)	164	19–89	4	.50
Primary/working memory–space				
Birren & Morrison (1961)	933	25–64	3	.37
Botwinick & Storandt (1974)	120	20–80	8	.18
Goldfarb (1941, men)	108	18–64	3	.19
Goldfarb (1941, women)	60	18–64	3	.15
Heron & Chown (1967, men)	300	20–79	2	.33
Heron & Chown (1967, women)	240	20–79	2	.38
Kirasic et al. (1996)	477	17–87	4	.11
Salthouse (1991b, Study 2)	228	20–82	4	.10
Salthouse (1991b, Study 3)	223	20–84	4	.14
Salthouse (1995b)	117	20–79	4	.27
Salthouse & Meinz (1995)	242	18–89	2	.31
Salthouse et al. (1989)	120	20–78	1	.38
Episodic memory–reasoning				
Aftanas & Royce (1969)	100	16–70	4	.13
Baltes & Lindenberger (1997)	171	25–69	1	.40
Bors & Forrin (1995)	63	26–80	1	.56
Clark (1960)	102	20–70	1	.59
Salthouse (1993)	305	19–84	12	.32
Salthouse (1994b, Study 1)	246	18–84	4	.31
Salthouse (1994b, Study 2)	258	20–87	1	.45
Salthouse, Fristoe, et al. (1996)	259	18–94	2	.46
Salthouse et al. (1988a, Study 2)	233	20–78	4	.30
Episodic memory–space				
Aftanas & Royce (1969)	100	16–70	2	.16
Botwinick & Storandt (1974)	120	20–80	10	.42
Clark (1990)	102	20–70	1	.40
Salthouse (1993)	305	19–84	6	.24
Salthouse (1994b, Study 1)	246	18–84	4	.23
Salthouse (1994b, Study 2)	258	20–87	1	.42
Salthouse (1995b)	117	20–79	2	.39
Salthouse, Fristoe, et al. (1996)	259	18–94	6	.39
Salthouse et al. (1988a, Study 1)	129	20–79	4	.27
Reasoning–space				
Aftanas & Royce (1969)	100	16–70	2	.44
Clark (1960)	102	20–70	1	.57
Heron & Chown (1967, men)	300	20–79	1	.62
Heron & Chown (1967, women)	240	20–79	1	.54
Salthouse (1991b, Study 2)	228	20–82	4	.28
Salthouse (1991b, Study 3)	223	20–84	4	.44
Salthouse (1993)	305	19–84	1	.49
Salthouse (1994b, Study 1)	246	18–84	4	.46
Salthouse (1994b, Study 2)	258	20–87	2	.54
Salthouse, Fristoe, et al. (1996)	259	18–94	3	.60
Salthouse & Mitchell (1990)	383	18–84	4	.58
Salthouse et al. (1989)	120	20–78	1	.66

Note. j = number of correlations averaged to obtain r.
[a] Age range not reported in original article (M age = 41 years, SD = 13). [b] Maximum age not reported in original article.

Table 2
Statistics for Mean Weighted Correlations

Type of correlation	k	N	M weighted correlation (r_+)	LL/UL of 95% confidence inferred	Homogeneity of sample (Q_T)
			Total sample		
Age–speed	50	11,044	−.52	−.53/−.50	247.82[a]
Age–PM/WM	34	6,831	−.27	−.29/−.25	119.37[a]
Age–EM	29	5,871	−.33	−.36/−.31	89.48[a]
Age–reasoning	38	9,342	−.40	−.42/−.39	216.35[a]
Age–space	36	10,942	−.38	−.40/−.36	106.65[a]
Speed–PM/WM	22	4,509	.37	.34/.39	88.61[a]
Speed–EM	26	5,482	.33	.31/.35	48.71[a]
Speed–reasoning	15	4,026	.55	.52/.57	200.03[a]
Speed–space	19	5,283	.40	.38/.42	129.65[a]
PM/WM–EM	11	1,732	.36	.32/.40	20.77[a]
PM/WM–reasoning	8	1,676	.45	.41/.49	21.94[a]
PM/WM–space	12	3,168	.27	.24/.30	47.76[a]
EM–reasoning	9	1,737	.38	.34/.42	26.91[a]
EM–space	9	1,636	.33	.28/.37	15.31[a]
Reasoning–space	12	2,764	.53	.50/.55	43.15[a]
			Largest joint cluster of studies only[b]		
Age–reasoning	32	8,302	−.39	−.41/−.37	72.23[a]
Speed–PM/WM	19	4,037	.40	.37/.42	36.73[a]
Speed–EM	24	5,147	.35	.32/.37	22.45
Speed–reasoning	11	2,459	.46	.43/.49	14.83
EM–reasoning	6	1,472	.38	.33/.42	8.56
Reasoning–space	11	2,536	.53	.52/.57	22.12[a]
			Data from Salthouse and colleagues only		
Age–speed[c]	28	4,153	−.50	−.52/−.48	84.84[a]
Age–PM/WM	14	2,580	−.33	−.36/−.29	47.02[a]
Age–EM	14	2,821	−.33	−.36/−.30	27.51[a]
Age–reasoning	10	2,476	−.36	−.40/−.33	45.27[a]
Age–space	12	2,642	−.36	−.39/−.33	35.42[a]
Speed–PM/WM	9	1,729	.42	.38/.46	23.00[a]
Speed–EM	11	2,220	.35	.32/.39	9.21
Speed–reasoning	8	2,123	.46	.42/.49	15.74[a]
Speed–space	9	2,261	.34	.30/.37	21.02[a]
PM/WM–EM	3	553	.31	.23/.38	3.61
PM/WM–reasoning	3	672	.47	.41/.53	11.84[a]
PM/WM–space	4	810	.20	.13/.26	7.50
EM–reasoning	5	1,294	.37	.32/.42	8.68
EM–space	6	1,314	.32	.27/.37	10.22
Reasoning–space	8	2,022	.51	.48/.54	33.90[a]

Note. LL = lower limit; UL = upper limit; PM/WM = primary/working memory; EM = episodic memory.
[a] Significant heterogeneity at $p < .05$. [b] Only reported if largest joint cluster is different from total sample.
[c] Only paper-and-pencil speed tests were included in this sample.

with these indices proved satisfactory (i.e., GFI = 0.97, AGFI = .91, NFI = 0.93, RMR = .042).

In the second step of the analysis, the paths from age to the cognitive variables were estimated while fixing the previously established coefficients to and from the common factor. Only paths that were significant ($p < .05$) were retained in the final model and are illustrated in Figure 1 by dotted lines. The chi-square statistic for the revised model indicated poor fit, $\chi^2(5, N = 4{,}809) = 380.63$, $p < .001$, but the other fit indices proved satisfactory and sometimes indicated better fit for this model than for the previous one (GFI = 0.97, AGFI = .89, NFI = 0.95, RMR = .047). A nested comparison revealed that the improvement in fit from the first to this final model was significant, that is, $\Delta\ \chi^2(3, N = 4{,}809) = 117.86$.

From these common factor models, one may conclude that the five cognitive variables share a considerable proportion of age-related variance, as indicated by the fact that they can be represented as being influenced by a common age-related latent factor. However, the second step in the analysis indicated that unique influences of age were evident on speed, primary–working memory, and reasoning. Although in comparison to the effects mediated through the common factor (i.e., the product of

Table 3
Statistics for Data From Salthouse and Colleagues

Type of coefficient	k	N	M weighted reliability (r_+)	LL/UL of 95% confidence inferred	Homogeneity of sample (Q_T)
			Total sample		
Speed	17	3,144	.90	.89/.91	220.55[a]
PM/WM	8	1,404	.85	.83/.86	68.77[a]
EM	8	1,661	.77	.75/.79	176.91[a]
Reasoning	2	353	.87	.84/.89	0.03
Space	6	999	.90	.89/.91	167.54[a]
			Under 50 years of age		
Speed	17	1,669	.88	.87/.89	93.05[a]
PM/WM	8	740	.84	.82/.86	40.32[a]
EM	8	833	.77	.74/.79	118.70[a]
Reasoning	2	181	.83	.78/.87	0.99
Space	6	515	.90	.88/.91	147.83[a]
			Over 50 years of age		
Speed	17	1,475	.88	.87/.89	124.54[a]
PM/WM	8	664	.84	.82/.86	32.16[a]
EM	8	828	.78	.75/.81	148.67[a]
Reasoning	2	172	.85	.80/.89	0.36
Space	6	484	.88	.85/.90	58.20[a]

Note. LL = lower limit; UL = upper limit; PM/WM = primary/working memory; EM = episodic memory.
[a] Significant heterogeneity at $p < .05$.

the age–common and common–variable paths), these direct effects were small (i.e., limits of the 95% CIs in the direction of zero are −.066 for the direct path from age to speed, .027 for the direct path from age to primary–working memory, and .023 for the direct path from age to reasoning) but noteworthy because they represent age-related influences that are independent of those mediated through the common factor. Because the direction of the unique effects is opposite to those from age

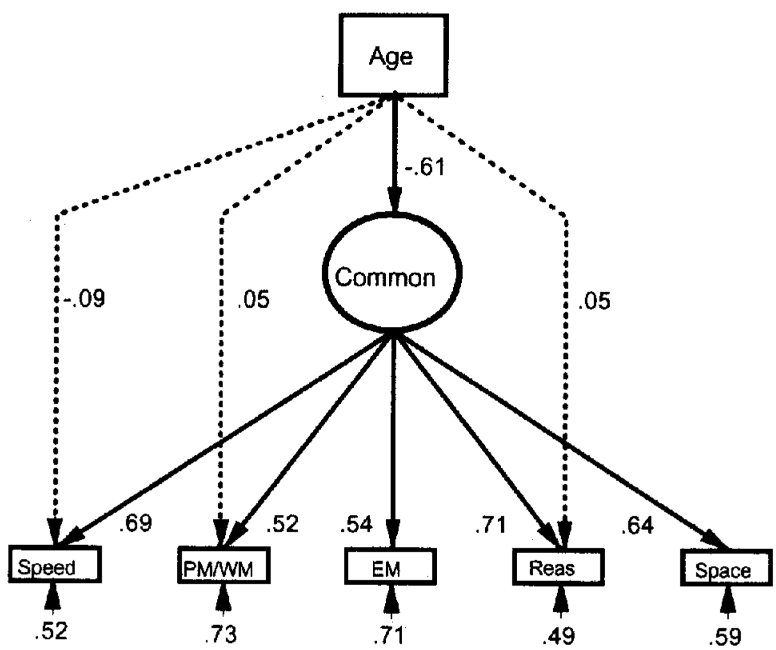

Figure 1. A single common factor structural model for the interrelations among age and five cognitive variables (PM/WM = primary–working memory; EM = episodic memory; Reas = reasoning).

to the common factor for primary–working memory and for reasoning, the age-related effects on these variables were overestimated by the common factor influence. However, the direction of the path from age to speed was the same as that from age to the common factor, and consequently the common influence can be inferred to underestimate the age-related effects on the measures of speed.

Structural equation modeling: The mediational model. The second set of structural models was based on the assumption that constructs of speed and primary–working memory partially mediate the influences of age on measures of episodic memory, reasoning, and spatial ability. The sequence of analyses was as follows. In accordance with the mediational model outlined in the beginning of this article, three categories were distinguished within the six variables: (a) age, (b) speed and primary–working memory, and (c) reasoning, space, and episodic memory. Successive stages in this categorization scheme represent the hypothesized flow of influence. All possible paths were estimated from an earlier category to a later category (i.e., from age to speed, primary/working memory, reasoning, space, and episodic memory; from speed to reasoning, space, and episodic memory; and from primary–working memory to reasoning, space, and episodic memory) as well as all paths within categories (i.e., from speed to primary–working memory and vice versa and all paths among reasoning, space, and episodic memory). Preliminary analyses revealed serious problems when fitting models with a reciprocal path between reasoning and space, which were moderately high intercorrelated ($r_+ = .53$). Models with a unidirectional influence between reasoning and space did fit the data, but an arbitrary choice then had to be made for the direction of the path (i.e., from reasoning to space or vice versa). Instead, we opted for the solution of letting reasoning and space load on a common latent factor (labeled Gf [General Fluid Intelligence]; Cattell, 1943; Horn & Cattell, 1963).

The resulting model fit the data quite well, with the understandable exception of the chi-square statistic, $\chi^2(1, N = 4{,}809) = 35.82, p < .001$, GFI = 1.00, AGFI = .95, NFI = 1.00, RMR = .011), although there were problems with the estimation of the error variance of primary–working memory, resulting in the incomputability of standard errors. Fixing the smallest path (from speed to episodic memory) to zero did not remediate this problem and did not affect the chi-square statistics, $\chi^2(2, N = 4{,}809) = 35.82$, $\Delta\chi^2(1, N = 4{,}809) = 0.00$. Fixing the next smallest path (from primary–working memory to speed) to zero resulted in a completely identifiable model, with no change in the chi-square statistic, $\chi^2(3, N = 4{,}809) = 35.82$, $\Delta\chi^2(2, N = 4{,}809) = 0.00$. Fixing the one nonsignificant path in this model to zero did not increase the chi-square statistic significantly, $\chi^2(4, N = 4{,}809) = 39.45$, $\Delta\chi^2(2, N = 4{,}809) = 3.63$. All paths in this final model were significant, and it provided an excellent fit to the data (GFI = 1.00, AGFI = .98, NFI = 1.00, RMR = .011).

This final mediational model, portrayed in Figure 2, shows that there is substantial mediation of the age-related effects on primary–working memory through speed, substantial mediation of age-related effects on Gf through speed and primary–working memory, and substantial mediation of age-related effects on episodic memory through speed, primary–working memory, and Gf. Total and mediated age effects were, respectively, −.27 and −.18 for primary–working memory, −.52 and −.24 for Gf, and −.33 and −.23 for episodic memory. This meta-analytically derived model is similar in most respects to models based on data from single studies (e.g., Park et al., 1996; Salthouse, 1993, 1994b).

As a quantitative indicator of the importance of the mediating role of speed and primary–working memory, the proportion of age-related variance in the cognitive variables that was shared with speed and primary–working memory was calculated by hierarchical regression, as outlined in Salthouse (1991c). That is, the total amount of age-related variance in the criterion variable is determined, and then the amount of unique or independent age-related variance is assessed by controlling the variance in speed, primary–working memory, or both. The complement of the ratio of unique over total age-related variance gives the proportion of age-related variance that is shared between the criterion variable and the hypothesized mediator. For primary–working memory, the percentage of age-related variance that was shared with speed was 92.5. For reasoning, 78.6% of the age-related variance was associated with speed, 40.4% with primary–working memory, and 82.3% with both speed and primary–working memory. For space, these percentages were 71.6, 29.5, and 74.1, respectively. For episodic memory, the percentages were 70.5, 45.8, and 76.4, respectively.

Age–Cognition Relations for Two Different Age Groups

Nonlinear effects of aging on cognition. The availability of the raw data from the relevant research projects conducted by Salthouse and colleagues gave us the opportunity to test for linear and quadratic effects of age on the five cognitive variables. To create estimates of the linear and quadratic effects amenable to meta-analytic pooling, we used the following procedure. First, the linear effect in the data is estimated from the correlation between age and the cognitive variable. Second, the quadratic effect is computed by first creating an age-square term in the original data, then taking the residuals of this term after controlling for age, and finally correlating these residuals with the cognitive variables to obtain an estimate of the quadratic age effect that is orthogonal to the linear effect (see Baltes & Lindenberger, 1997, for another application of this method). The resulting linear and quadratic effects are Pearson correlations and can thus be subjected to meta-analysis according to the procedure described in the Method section. The results from this analysis can be found in Table 4. Significant quadratic trends in the age–cognition relations were found for the variables of speed and reasoning, in each case indicating that the decline in functioning for these two variables was accelerating with advancing age. It is also noteworthy that although not statistically significant, the trend was in the same direction for the other variables, primary–working memory, episodic memory (where the upper limit of the 95% CI was .0002), and space.

Another way of examining nonlinear effects is by considering age–cognition correlations of adults of different ages. In our analysis, we divided the total sample into subsamples under and over 50 years old because Age 50 was close to the median age in most of the samples. As noted above, data for these analyses were based only on studies by Salthouse and colleagues because they required separate correlation matrices for each age group,

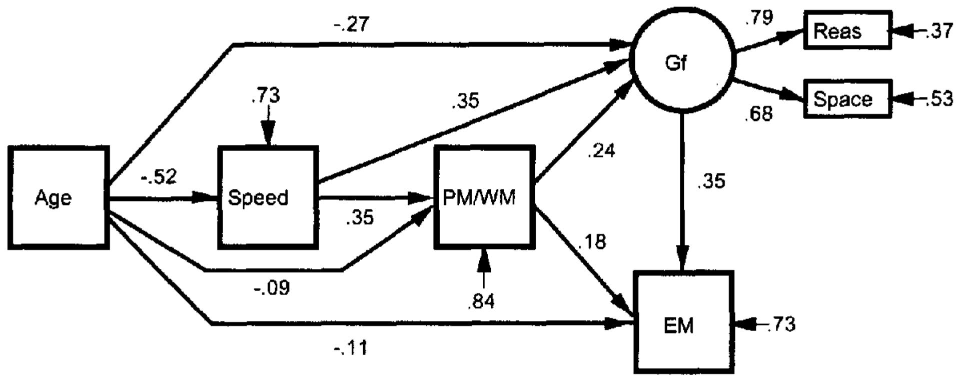

Figure 2. A mediational structural model for the interrelations among age and five cognitive variables (PM/WM = primary/working memory; Gf = General Fluid Intelligence; EM = episodic memory; Reas = reasoning).

which were not available in published articles from other data sets. For the comparisons in the two samples to be meaningful, reliability must be demonstrated to be comparable in the two samples. Reliability coefficients for the two groups can be found in Table 3. None of the Q_B tests for differential reliability was significant, suggesting that the reliability estimates for all measures were equivalent in these two groups.

The mean weighted correlations for both age groups—along with 95% CIs, within-group homogeneity values, and the between-group homogeneity test values—are presented in Table 5. Significant differences in the age–cognition relations (as indexed by significant nonhomogeneity in the Q_B statistic) were found for the variables of speed (for reasons explained below, only paper-and-pencil speed measures were included in the table, but the correlations were also significant when all speed measures were used, $k = 28$; for the younger sample: $N = 2{,}892$, $r_+ = -.27$, LL/UL $= -.30/-.24$, $Q_T = 36.88$, $p < .05$; for the older sample: $N = 2{,}393$, $r_+ = -.37$, LL/UL $= -.41/-.34$, $Q_T = 35.17$, $p < .05$; $Q_B = 16.66$, $p < .05$), reasoning, and episodic memory. In each of these three cases, the difference in the age–cognition relation between the two age groups indicates that the relation between age and the cognitive variable is stronger in people older than 50 years than in people younger than 50 years. Because the age range was approximately 30 years in both age groups, this difference between correlations implies that the age-related decline in functioning for these three variables was accelerating with advancing age. It is also noteworthy, although not statistically significant, that the trend was in the same direction for the other two variables, primary–working memory and space. Thus, these results largely converge with the results of the more direct nonlinearity analyses reported above.

Structural equation modeling: The common factor model. The correlation matrices for the under 50 and over 50 years old groups were entered in a group-comparison structural analysis to examine the effects of age on the paths in the common factor model. Because both matrices are correlation matrices, that is, they are covariance matrices standardized on the within-age group standard deviations, it is important to examine the variability of the cognitive measures in the two age groups to determine whether there were substantial differences in variability that might affect the estimates of the relations. A ratio of the variance of older adults over the variance of young adults was, therefore, derived for each of the measures for each study. These estimates were pooled, and weighting for sample size and *t* tests were used to determine whether the average weighted ratio was different from unity. Only the variance ratio for speed was significantly different from unity ($M = 1.58$, $SD = 0.88$); the

Table 4
Statistics for Age–Cognition Relations in Data From Salthouse and Colleagues

			Linear			Quadratic		
Type of relation	k	N	M weighted coefficient (r_+)	LL/UL of 95% CI	Homogeneity of sample (Q_T)	M weighted coefficient (r_+)	LL/UL of 95% CI	Homogeneity of sample (Q_T)
Age–speed	28	5,372	−.50	−.52/−.48	91.39[a]	−.07	−.10/−.05	15.77[a]
Age–PM/WM	14	2,580	−.33	−.36/−.29	47.02[a]	−.02	−.06/.01	25.61[a]
Age–EM	14	2,821	−.33	−.36/−.30	27.51[a]	−.04	−.08/.00	9.99
Age–reasoning	10	2,476	−.36	−.40/−.33	45.27[a]	−.07	−.11/−.03	24.90[a]
Age–space	12	2,642	−.36	−.39/−.33	33.42[a]	−.02	−.06/.02	9.60

Note. LL = lower limit; UL = upper limit; CI = confidence inferred; PM/WM = primary/working memory; EM = episodic memory.
[a] Significant heterogeneity at $p < .05$.

Table 5
Statistics for Subsamples of Adults Under and Over 50 Years of Age

Type of correlation	Under 50 years of age: k	N	M weighted correlation (r_+)	LL/UL of 95% CI	Homogeneity of sample (Q_T)	Over 50 years of age: N	M weighted correlation (r_+)	LL/UL of 95% CI	Homogeneity of sample (Q_T)	Age group differnece (Q_B)
Age–speed	28	2,892	−.27	−.30/−.24	36.88	2,393	−.37	−.41/−.34	35.17	16.66[a]
Age–PM/WM	14	1,370	−.19	−.24/−.14	29.79[a]	1,158	−.24	−.29/−.18	26.70[a]	1.51
Age–EM	14	1,439	−.15	−.20/−.10	20.15	1,298	−.23	−.28/−.18	17.84	4.97[a]
Age–reasoning	10	1,284	−.14	−.19/−.08	29.11[a]	1,132	−.28	−.33/−.23	9.89	13.64[a]
Age–space	12	1,297	−.18	−.23/−.13	17.99	1,068	−.25	−.31/−.20	24.76[a]	3.09
Speed–PM/WM	12	1,213	.31	.26/.36	10.46	980	.35	.29/.40	13.66	1.14
Speed–EM	13	1,321	.24	.19/.29	10.24	1,187	.30	.25/.35	10.68	3.11
Speed–reasoning	8	1,109	.37	.31/.41	10.82	966	.47	.42/.51	5.14	7.85[a]
Speed–space	10	1,248	.25	.20/.30	11.60	1,085	.32	.26/.37	25.94[a]	2.88
PM/WM–EM	3	280	.29	.18/.39	6.95[a]	264	.29	.17/.39	0.42	0.00
PM/WM–reasoning	3	346	.40	.31/.49	5.37	326	.37	.27/.46	10.15[a]	0.26
PM/WM–space	4	413	.18	.09/.27	1.90	385	.08	−.02/.17	11.39[a]	2.19
EM–reasoning	5	670	.30	.23/.37	19.62[a]	613	.32	.25/.39	3.20	0.18
EM–space	6	688	.26	.19/.33	9.53	608	.27	.20/.34	2.55	0.06
Reasoning–space	8	1,073	.48	.43/.52	16.63[a]	925	.46	.41/.51	21.83[a]	0.11

Note. LL = lower limit; UL = upper limit; CI = confidence inferred; PM/WM = primary/working memory; EM = episodic memory.
[a] Significant heterogeneity at $p < .05$.

other ratios were all close to 1.0 (primary–working memory, $M = 0.91$, $SD = 0.17$; episodic memory, $M = 1.01$, $SD = 0.24$; reasoning, $M = 1.33$, $SD = 0.62$; space, $M = 0.92$, $SD = 0.32$). When the speed measures were split into a subsample of paper-and-pencil versus reaction time measures, however, it was found that the variance ratio was different from unity for the reaction time measures ($M = 2.32$, $SD = 1.34$) but not for the paper-and-pencil measures ($M = 1.00$, $SD = 0.13$). Consequently, we decided to drop all reaction time measures from the computation of the correlation matrix, which was used as input for the two-group structural equation models.

The common factor model was fitted to the two-group data ($N = 1{,}046$ and 920, respectively, for the under 50 and over 50 years old groups).[6] First, paths were estimated from age to the common factor and from the common factor to the cognitive variables, fixing all paths (including error variances[7]) to be equal across age groups. Fit of this model proved satisfactory, $\chi^2(29, N = 1{,}966) = 248.40$, GFI = 0.95, NFI = 0.87, RMR = .067, but it could be improved significantly by allowing the paths from age to the common factor and from the common factor to speed to differ across groups, freeing age–common, $\chi^2(28, N = 1{,}966) = 237.66$, GFI = 0.96, NFI = 0.88, RMR = .060, $\Delta\ \chi^2(1, N = 1{,}966) = 10.74$; and freeing common–speed, $\chi^2(27, N = 1{,}966) = 231.25$, GFI = 0.96, NFI = 0.88, RMR = .057, $\Delta\ \chi^2(1, N = 1{,}966) = 6.41$. The resulting paths are depicted by solid lines in Figure 3. When only one coefficient was displayed, the two groups did not differ in the parameter; when two coefficients were presented, the first coefficient corresponded to the under 50 years old group and the second to the over 50 years old group. In the second step of the analysis, the paths from age to the cognitive variables were estimated while the previously established coefficients were fixed to and from the common factor. In both groups, the path from age to speed and from age to reasoning was significant. Fixing the path from age to speed and from age to reasoning to be equal across groups did not significantly affect the solution as compared with letting the paths vary between group, $\Delta\ \chi^2(2, N = 1{,}966) = 0.73$. The final model is shown in Figure 3, with the paths that fit in the second step indicated by dotted lines. This model fit the data well, $\chi^2(25, N = 1{,}966) = 182.59$, GFI = 0.96, NFI = 0.91, RMR = .058). Limits of the 95% CI closest to zero for the specific paths were −.032 for the path from age to speed in the younger sample and .058 for the path from age to reasoning in both samples.

An inspection of Figure 3 reveals that only two paths differed significantly between the under 50 and over 50 years old age groups. These differences suggest that (a) in older age, speed becomes a more important defining variable for the common factor, as indicated by the larger path from the common factor

[6] The fit statistics for the common factor model with the complete age range using the Salthouse studies only (the direct age–variable paths freed were those between age and speed and between age and reasoning) were $\chi^2(6, N = 1{,}966) = 233.93$, GFI = 0.97, AGFI = .94, NFI = 0.92, RMR = .054.

[7] Allowing error variance to differ between age groups did not significantly affect the fit of the final solution, $\Delta\ \chi^2(5, N = 1{,}966) = 10.99$. It should be noted, however, that in this analysis the direct path between age and speed became nonsignificant in the older age group.

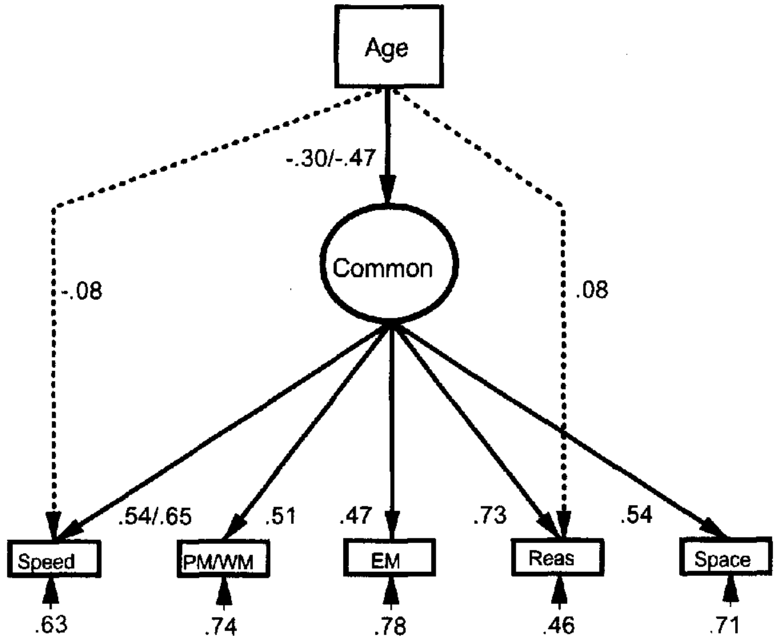

Figure 3. A single common factor structural model for the interrelations among age and five cognitive variables for age groups under and over 50 years (PM/WM = primary/working memory; EM = episodic memory; Reas = reasoning).

to speed in the over 50 years old group, and (b) the impact of age on the common factor is larger in the older age group.

Structural equation modeling: The mediational model. The initial model in the two-group mediational analysis was the final mediational model from the total sample (see Figure 2).[8] In a first step, coefficients (including error variances[9]) were constrained for the two groups to be equal, $\chi^2(24, N = 1{,}966) = 135.61$, GFI = 0.97, NFI = 0.93, RMR = .055. In an exploratory effort to detect age differences in the coefficients, this model was then relaxed by allowing path coefficients to differ between groups. One path was freed at a time, in such a way that the difference in the chi-square statistic between the relaxed model and the last estimated model was maximal. This procedure was repeated until no significant improvement was possible. The sequence of paths freed to be different between groups was the (a) path from age to speed, $\chi^2(23, N = 1{,}966) = 124.31$; (b) path from primary–working memory to Gf, $\chi^2(22, N = 1{,}966) = 119.61$; (c) path from age to Gf, $\chi^2(21, N = 1{,}966) = 112.13$; and (d) path from speed to Gf, $\chi^2(20, N = 1{,}966) = 106.39$. The final model resulting from these steps is illustrated in Figure 4. When only one coefficient was displayed, the two groups did not differ in the parameter; when two coefficients were presented, the first coefficient corresponded to the under 50 years old group and the second to the over 50 years old group. This model fit the data well (i.e., GFI = 0.98, NFI = 0.95, RMR = .040).

An inspection of Figure 4 reveals that only four paths differed significantly between the under 50 and over 50 years old groups. Two of these involved weaker correlations from age to speed and from age to Gf in the younger sample, which reflect the larger age relations for these variables in the older age group (cf. Table 3). The path from speed to Gf is also larger in the older age group. However, it is noteworthy that the direct relations between age and episodic memory are not significantly larger in the older group; thus the larger total relations between age and episodic memory in the older group seem to be due to greater mediated effects rather than to stronger direct effects of age. The other significant age difference was a stronger relation of primary–working memory to Gf in the under 50 years old group. This is somewhat surprising and may be an artifactual consequence of the smaller direct age-related influences on speed and Gf and the smaller influence from speed to Gf in the younger sample.

Discussion

There are two major sets of results in this project: (a) the meta-analytical estimates of the relations between age and five categories of cognitive variables and (b) the structural models of the nature of the relations between age and measures of cognitive functioning. Each of these results is discussed in turn.

The meta-analytical results indicate that the largest age relations were apparent on the measures of speed (a linear correlation of −.52, −.54 after correction for attenuation). This is not surprising because speed measures have often been recognized as being very sensitive to age-related influences (e.g., Salthouse,

[8] The fit statistics for the mediational model with the complete age range using the Salthouse data only were $\chi^2(4, N = 1{,}966) = 138.58$, GFI = 0.98, AGFI = .88, NFI = 0.95, RMR = .036.

[9] Allowing error variance to differ between age groups did not significantly affect the fit of the final solution, $\chi^2(5, N = 1{,}966) = 4.16$.

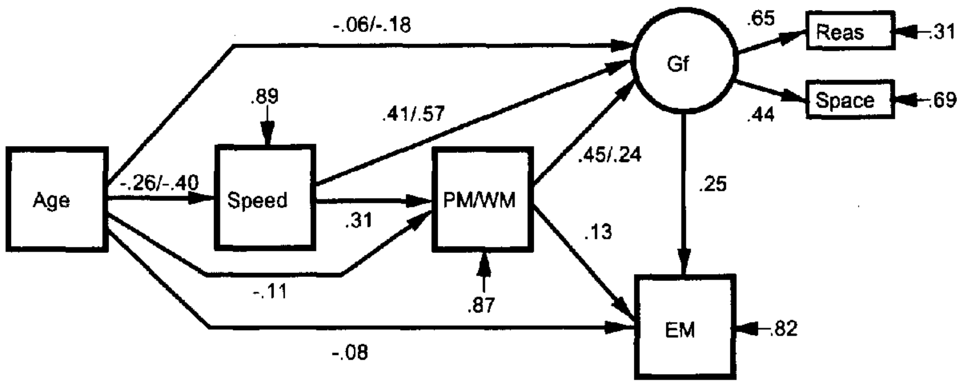

Figure 4. A mediational structural model for the interrelations among age and five cognitive variables for age groups under and over 50 years (PM/WM = primary/working memory; Gf = General Fluid Intelligence; EM = episodic memory; Reas = reasoning).

1985, 1996b). Age–cognition correlations were similar in magnitude for measures of reasoning, spatial ability, and episodic memory, especially after unreliability had been taken into account ($r_+ = -.40$, $-.38$, and $-.33$ before correction for attenuation; $-.42$, $-.40$, and $-.38$ after correction for attenuation). Age appears to have less impact on measures of primary–working memory (a linear correlation of $-.27$, $-.29$ after correction for attenuation), but this result was largely due to the smaller age relations on measures of primary memory ($r_+ = -.19$) compared with working memory ($r_+ = -.36$).

Analysis of quadratic age effects reveal that significant negative quadratic age–cognition relations, indicating accelerating decline over the adult life span, were evident for measures of perceptual speed and reasoning ability. For the other variables, nonsignificant trends were in the same direction; the trend was close to significant for measures of episodic memory. The analyses on individuals over and under the age of 50 demonstrate that the age relations as measured by linear correlations were stronger in the older group and significantly so for speed, reasoning, and episodic memory. The discovery in this large sample of studies that age-related declines in measures of fluid cognition tend to accelerate in later adulthood is interesting because, as mentioned in the beginning of this article, many different positions regarding the pattern of decline in fluid cognition have been advanced in the literature. It is also important to note that there are significant age-related effects in all variables in the sample ranging from 18 to 50 years of age. These results clearly indicate that it is not the case that age-related effects only emerge after the age of 50 (or even later), as has sometimes been claimed (e.g., Cunningham, 1987; Labouvie-Vief, 1977; Lehman & Mellinger, 1986). Although it is true that the influences related to age are stronger after the age of 50, they are clearly different from zero in the range from 18 to 50 years of age. Another interesting finding was that the reliabilities and variances for most of the variables were comparable for individuals over and under the age of 50. Moreover, detailed examination of the structural pattern among variables suggests that the interrelations of the variables were quite similar in the two age groups. The model resulting from the structural equation modeling analysis suggests that the accelerated decline in the older sample (indicated in the two-group analysis as larger age–cognition correlations in the older age group) is a direct age-related effect (i.e., not mediated by any of the variables in our analyses) for the measure of speed and partly so for reasoning, whereas most of the larger age effects in measures of episodic memory seem to be explained by the higher age–speed and age–Gf correlations in the older sample.

Two types of structural models were examined with the meta-analytically derived correlation estimates. An important finding in both types of analysis was that the age-related influences on different cognitive variables were not independent of one another. This is apparent both in the model with a single common factor and in the model with speed and primary–working memory as the hypothesized mediators. Only if most of the age-related effects could be modeled with direct paths from age to the individual variables could one conclude that age-related effects on the different cognitive variables are largely independent of each other. This is clearly not the case. In the single common factor model, the direct paths from age to the variables were significant for only three variables and were generally small in magnitude; in the mediated model, the indirect (i.e., mediated) effects of age were generally larger than the direct effects.

That the data fit well by the common factor model has implications for theories of cognitive aging. In particular, these results lend support to the common cause hypothesis (Baltes & Lindenberger, 1997; Lindenberger & Baltes, 1994), which states that (a) no single ability construct acts as a proximal cause of negative age decrements in the other constructs and (b) differences in the magnitude of the age–cognition correlations are determined by differences in the magnitude of loadings on the common factor: The higher the loading, the greater the negative relation with age. The number and magnitude of the direct paths from age to cognition provide an indication of the extent to which the latter of the two conditions is inconsistent with the data. That there are significant direct paths from age to some of the cognitive variables (i.e., to speed, primary–working memory, or reasoning) indicates that the simplest, and most extreme, version of the common factor model is inadequate. Moreover, the discovery in the two-group analyses that speed appears to become more important in defining the common factor at later ages suggests that the speed variable may deserve special status in the context of cognitive aging: Its relation to age is clearly larger than can be explained by a common factor model that is invariant over the adult life span.

The mediational model that we examined assumes that constructs of speed and primary–working memory are more fundamental or basic than constructs representing other cognitive abilities and that at least some of the age-related influences on measures of episodic memory, reasoning, and spatial ability are mediated through age-related effects on these more elementary constructs. These assumptions fit the data well. Moreover, hierarchical regression analysis reveals that between 71% and 79% of the age-related variance in the cognitive variables was shared with speed; including primary–working memory as an additional predictor increased these percentages to between 74 and 82. Clearly, age-related declines in speed and working memory capacity, efficiency, or both appear to be involved in the age-related decline evident in more complex aspects of cognition. A number of speculations have been offered about the mechanisms that might be responsible for the speed and working memory relation (e.g., Salthouse, 1992b, 1996b), but regardless of their ultimate accuracy, the results of our analyses clearly indicate that a large proportion of the age-related variance in different cognitive variables is shared with speed and working memory. Complete theories about cognitive aging, therefore, will need to take the influence of these variables into account.

It is important to emphasize that none of the results we have discussed are consistent with interpretations based on a single, monolithic determinant of the age-related effects on cognitive functioning. Direct paths from age to several cognitive variables were found in both the single common factor and mediational models, indicating that even under fairly conservative conditions independent influences of age (i.e., nonmediated by variables in the model) can be detected. An important goal for future research is to investigate the nature, and to assess the relative importance, of different factors contributing to age-related effects on measures of cognitive functioning. Statistical control procedures such as those described above can be used for this purpose, but other techniques, such as experimental dissociation procedures (e.g., Kliegl, Mayr, & Krampe, 1994), should also be explored.

Finally, we should acknowledge some of the limitations of this approach. First, the data used in these analyses were all cross-sectional in nature; thus strong conclusions regarding the causality of effects cannot be drawn. It would be interesting to determine whether the same patterns of relations would be replicated in longitudinal data sets, although it may be some time before a sufficient number of studies is available to allow these types of meta-analyses of longitudinal data. Second, our models were limited to the five types of cognitive variables most often used in aging research. In this data set, we concentrated on the mediational influence of speed and primary–working memory, as postulated in a number of existing theories. However, other potential mediators or predictors of age–cognition relations, such as sensory measures (e.g., Lindenberger & Baltes, 1994), inhibition measures (e.g., Hasher & Zacks, 1988), or more direct indicators of brain functioning, were not examined in this meta-analysis for purely pragmatic reasons (i.e., the small numbers of relevant studies). Third, because the search for age–cognition correlation matrices in continuous age samples could not be accomplished by an automated search, we cannot be sure that this database is exhaustive. Even though every effort was made to incorporate as many studies as possible, some studies may have been inadvertently overlooked. Fourth, the meta-analytic data set was not as ideally suited for linear structural modeling as one might have wished. Significant heterogeneity remained even after disjoint clusters were taken out, indicating that the correlations used are not precise point estimates of a true population correlation coefficient. Significant nonlinearity was detected for some measures, implying that the linear structural modeling technique (using linear estimates) could result in misleading estimates of the true relation among the variables.

Conclusion

In summary, meta-analyses of correlations between age and different measures of cognition revealed that the age relations in this literature are somewhat stronger with measures of speed than with measures of reasoning, spatial abilities, and working and episodic memory and that primary memory has a smaller age relation than do the latter variables. Significant nonlinearity in the age relation, indicating acceleration of the age deficit with advancing age, was found for the variables of speed and reasoning; for the other variables, the trend was in the same direction. Comparisons across age groups indicated that the influence of age was generally greater for those over the age of 50 than for those under the age of 50, but sizable relations were evident in both age ranges, indicating that cognitive performance declines with increased age even before the age of 50. Several alternative structural models were found to be consistent with the data, but each had two characteristics in common: (a) A relatively large proportion of the age-related influences on different cognitive variables was shared and (b) multiple independent factors need to be postulated to account for all of the age-related effects on cognitive variables.

References

References marked with an asterisk indicate studies included in the meta-analysis.

*Aftanas, M. S., & Royce, J. R. (1969). Analysis of brain damage tests administered to normal subjects with factor score comparisons across age. *Multivariate Behavioral Research, 4,* 459–481.

*Albert, M. S., Heller, H. S., & Milberg, W. (1988). Change in naming ability with age. *Psychology and Aging, 3,* 173–178.

*Arenberg, D. (1988). Analysis and synthesis in problem solving and aging. In M. L. Howe & C. J. Brainerd (Eds.), *Cognitive development in adulthood* (pp. 161–183). New York: Springer-Verlag.

Baddeley, A. (1986). *Working memory.* Oxford, England: Clarendon Press.

*Baltes, P. B., & Lindenberger, U. (1997). Emergence of a powerful connection between sensory and cognitive functions across the adult life span: A new window to the study of cognitive aging? *Psychology and Aging, 12,* 12–21.

Bangert-Drowns, R. L. (1986). Review of recent developments in meta-analytic method. *Psychological Bulletin, 99,* 388–399.

*Barr, R. A., & Giambra, L. M. (1990). Age-related decrement in auditory selective attention. *Psychology and Aging, 5,* 597–599.

*Barrett, G. V., Mihal, W. L., Panek, P. E., Sterns, H. L., & Alexander, R. A. (1977). Information processing skills predictive of accident involvement for younger and older commercial drivers. *Industrial Gerontology, 4,* 173–182.

*Birren, J. E., & Morrison, D. F. (1961). Analysis of the WAIS subtests in relation to age and education. *Journal of Gerontology, 16,* 363–369.

Bollen, K. A. (1989). *Structural equations with latent variables.* New York: Wiley.

*Bors, D. A., & Forrin, B. (1995). Age, speed of information processing, recall, and fluid intelligence. *Intelligence, 20,* 229–248.

*Botwinick, J., & Storandt, M. (1974). *Memory, related functions and age.* Springfield, IL: Charles C Thomas.

*Bromley, D. B. (1991). Aspects of written language production over adult life. *Psychology and Aging, 6,* 296–308.

*Bunce, D. J., Barrowclough, A., & Morris, I. (1996). The moderating influence of physical fitness on age gradients in vigilance and serial choice responding tasks. *Psychology and Aging, 11,* 671–682.

*Bunce, D. J., Warr, P. B., & Cochrane, T. (1993). Blocks in choice responding as a function of age and physical fitness. *Psychology and Aging, 8,* 26–33.

*Burke, H. R. (1972). Raven's Progressive Matrices: Validity, reliability, and norms. *Journal of Psychology, 82,* 253–257.

Cattell, R. B. (1943). The measurement of adult intelligence. *Psychological Bulletin, 40,* 153–193.

Cerella, J. (1990). Aging and information processing rate. In J. E. Birren & K. W. Schaie (Eds.), *Handbook of the psychology of aging* (3rd ed., pp. 201–221). San Diego, CA: Academic Press.

*Charness, N. (1987). Component processes in bridge bidding and novel problem-solving tasks. *Canadian Journal of Psychology, 41,* 223–243.

*Chown, S. M. (1961). Age and the rigidities. *Journal of Gerontology, 16,* 353–362.

*Clark, J. W. (1960). The aging dimension: A factorial analysis of individual differences with age on psychological and physiological measurements. *Journal of Gerontology, 15,* 183–187.

*Cohn, N. B., Dustman, R. E., & Bradford, D. C. (1984). Age-related decrements in Stroop color test performance. *Journal of Clinical Psychology, 40,* 1244–1250.

*Cornelius, S. W. (1984). Classic pattern of intellectual aging: Test familiarity, difficulty and performance. *Journal of Gerontology, 39,* 201–206.

*Crook, T. H., & West, R. L. (1990). Name recall performance across the adult life-span. *British Journal of Psychology, 81,* 335–349.

*Crosson, C. W. (1984). Age and field independence among women. *Experimental Aging Research, 10,* 165–170.

Cudeck, R. (1989). Analysis of correlation matrices using covariance structure models. *Psychological Bulletin, 105,* 317–327.

Cunningham, W. R. (1987). Intellectual abilities and age. In K. W. Schaie (Ed.), *Annual review of gerontology and geriatrics* (Vol. 7, pp. 117–134). New York: Springer.

*Davies, A. D., & Leytham, G. W. (1964). Perception of verticality in adult life. *British Journal of Psychology, 55,* 315–320.

*Dirken, J. M. (1972). *Functional age of industrial workers.* Groningen, The Netherlands: Wolters-Noordhoff.

Earles, J. L., & Salthouse, T. A. (1995). Interrelations of age, health, and speed. *Journal of Gerontology: Psychological Sciences, 50B,* P33–P41.

*Edwards, A. E., & Wine, D. B. (1963). Personality changes with age: Their dependency on concomitant intellectual decline. *Journal of Gerontology, 18,* 182–184.

*Fastenau, P. S., Denburg, N. L., & Abeles, N. (1996). Age differences in retrieval: Further support for the resource-reduction hypothesis. *Psychology and Aging, 11,* 140–146.

*Goldfarb, W. (1941). *An investigation of reaction time in older adults* (Contributions to Education No. 831). New York: Teachers College, Columbia University Press.

*Graf, P., & Uttl, B. (1995). Component processes of memory: Changes across the adult lifespan. *Swiss Journal of Psychology, 54,* 113–130.

Halstead, W. C. (1947). Brain and intelligence. Chicago: University of Chicago Press.

Hasher, L., & Zacks, R. T. (1988). Working memory, comprehension, and aging: A review and new view. In G. Bower (Ed.), *The psychology of learning and motivation* (pp. 193–225). New York: Academic Press.

Hedges, L. V., & Olkin, I. (1985). *Statistical methods for meta-analysis.* Orlando, FL: Academic Press.

*Heron, A., & Chown, S. (1967). *Age and function.* Boston: Little, Brown.

*Hooper, F. H., Hooper, J. O., & Colbert, K. C. (1984). *Personality and memory correlates of cognitive functioning.* Basel, Switzerland: Karger.

Horn, J. L., & Cattell, R. B. (1963). Age differences in fluid and crystallized intelligence. *Acta Psychologica, 26,* 107–129.

*Horn, J. L., Donaldson, G., & Engstrom, R. (1981). Apprehension, memory, and fluid intelligence decline in adulthood. *Research on Aging, 3,* 33–84.

*Hoyer, W. J., Rebok, G. W., & Sved, S. M. (1979). Effects of varying irrelevant information on adult age differences in problem solving. *Journal of Gerontology, 34,* 553–560.

Hultsch, D. F., Hertzog, C., & Dixon, R. A. (1990). Ability correlates of memory performance in adulthood and aging. *Psychology and Aging, 5,* 356–368.

Jöreskog, K. G., & Sörbom, D. (1993). *LISREL 8: Structural equation modeling with the SIMPLIS command language.* Hillsdale, NJ: Erlbaum.

Just, M. A., & Carpenter, P. A. (1992). A capacity theory of comprehension: Individual differences in working memory. *Psychological Review, 99,* 122–149.

*Kaufman, A. S., Reynolds, C. R., & McLean, J. E. (1989). Age and WAIS-R intelligence in a national sample of adults in the 20-to-74-year age range: A cross-sectional analysis with educational level controlled. *Intelligence, 13,* 235–253.

*Kausler, D. H. (1994). *Learning and memory in normal aging.* San Diego, CA: Academic Press.

*Kirasic, K. C., Allen, G. L., Dobson, S. H., & Binder, K. S. (1996). Aging, cognitive resources, and declarative learning. *Psychology and Aging, 11,* 658–670.

Kliegl, R., & Mayr, U. (1992). "Shifting levels of analysis in the investigation of cognitive aging": Commentary. *Human Development, 35,* 343–349.

Kliegl, R., Mayr, U., & Krampe, R. T. (1994). Time–accuracy functions for determining process and person differences: An application to cognitive aging. *Cognitive Psychology, 26,* 134–164.

*Koss, E., Haxby, J. V., DeCarli, C., Shapiro, M. B., Friedland, R. P., & Rapoport, S. I. (1991). Patterns of performance preservation and loss in healthy aging. *Developmental Neuropsychology, 7,* 99–113.

*Kraus, J., Chalker, S., & Macindoe, I. (1967). Vocabulary and chronological age as predictors of "abstraction" on the Shipley–Hartford Retreat Scale. *Australian Journal of Psychology, 19,* 133–135.

Labouvie-Vief, G. (1977). Adult cognitive development: In search of alternative interpretations. *Merrill Palmer Quarterly, 23,* 228–264.

*Lee, J. A., & Pollack, R. A. (1978). The effects of age on perceptual problem-solving strategies. *Experimental Aging Research, 4,* 37–54.

Lehman, E. B., & Mellinger, J. C. (1986). Forgetting rates in modality memory for young, mid-life, and older women. *Psychology and Aging, 1,* 178–179.

Lindenberger, U., & Baltes, P. B. (1994). Sensory functioning and intelligence in old age: A strong connection. *Psychology and Aging, 9,* 339–355.

Lindenberger, U., Mayr, U., & Kliegl, R. (1993). Speed and intelligence in old age. *Psychology and Aging, 8,* 207–220.

Loehlin, J. C. (1987). *Latent variable models: An introduction to factor, path and structural analysis.* Hillsdale, NJ: Erlbaum.

*Mason, C. F., & Ganzler, H. (1964). Adult norms for the Shipley Institute of Living Scale and Hooper Visual Organization Test based on age and education. *Journal of Gerontology, 19,* 419–424.

*McArdle, J. J., & Prescott, C. A. (1992). Age-based construct validation using structural equation modeling. *Experimental Aging Research, 18,* 87–115.

*McCrae, R. R., Arenberg, D., & Costa, P. T. (1987). Declines in divergent thinking with age: Cross-sectional, longitudinal, and cross-sequential analyses. *Psychology and Aging, 2,* 130–137.

*Meinz, E. J., & Salthouse, T. A. (in press). Effects of age and domain-relevant experience on memory for spatial information. *Journals of Gerontology: Psychological Sciences.*

Myerson, J., & Hale, S. (1993). General slowing and age invariance in cognitive processing: The other side of the coin. In J. Cerella, J. Rybash, W. Hoyer, & M. L. Commons (Eds.), *Adult information processing: Limits on loss* (pp. 115–141). San Diego, CA: Academic Press.

Myerson, J., Hale, S., Wagstaff, D., Poon, L. W., & Smith, G. A. (1990). The information-loss model: A mathematical theory of age-related cognitive slowing. *Psychological Review, 97,* 475–487.

Orme, J. E. (1957). Non-verbal and verbal performance in normal old age, senile dementia, and elderly depression. *Journal of Gerontology, 12,* 408–413.

*Park, D. C., Smith, A. D., Lautenschlager, G., Earles, J., Frieske, D., Zwahr, M., & Gaines, C. (1996). Mediators of long-term memory performance across the life span. *Psychology and Aging, 11,* 621–637.

*Perlmutter, M., & Nyquist, L. (1990). Relationships between self-reported physical and mental health and intelligence performance across adulthood. *Journals of Gerontology: Psychological Sciences, 45,* P145–P155.

*Pierce, T. W., Elias, M. W., Keohane, P. J., Podraza, A. M., Robbins, M. A., & Schultz, N. R. (1989). Validity of a short form of the Category test in relation to age, education, and gender. *Experimental Aging Research, 15,* 137–141.

Premack, S. L., & Hunter, J. E. (1988). Individual unionization decisions. *Psychological Bulletin, 103,* 223–234.

*Prigatano, G. P., & Parsons, O. A. (1976). Relationship of age and education to Halstead test performance in different patient populations. *Journal of Consulting and Clinical Psychology, 44,* 527–533.

Rabbitt, P. M. (1990). Applied cognitive gerontology: Some problems, methodologies and data. *Applied Cognitive Psychology, 4,* 225–246.

Rabbitt, P. M., & Abson, V. (1990). "Lost and found": Some logical and methodological limitations of self-report questionnaires as tools to study cognitive ageing. *British Journal of Psychology, 81,* 1–16.

Raven, J. C. (1960). Progressive Matrices: Revised manual. London: Lewis.

*Riege, W. H., & Inman, V. (1981). Age differences in nonverbal memory tasks. *Journal of Gerontology, 36,* 51–58.

*Robertson-Tchabo, E. A., & Arenberg, D. (1976). Age differences in cognition in healthy educated men: A factor analysis of experimental measures. *Experimental Aging Research, 2,* 75–89.

Salthouse, T. A. (1985). Speed of behavior and its implications for cognition. In J. E. Birren & K. W. Schaie (Eds.), *Handbook of the psychology of aging* (2nd ed., pp. 400–426). New York: Van Nostrand Reinhold.

*Salthouse, T. A. (1991a). Age and experience effects on the interpretation of orthographic drawings of three-dimensional objects. *Psychology and Aging, 6,* 426–433.

*Salthouse, T. A. (1991b). Mediation of adult age differences in cognition by reductions in working memory and speed of processing. *Psychological Science, 2,* 179–183.

Salthouse, T. A. (1991c). *Theoretical perspectives on cognitive aging.* Hillsdale, NJ: Erlbaum.

*Salthouse, T. A. (1992a). Influence of processing speed on adult age differences in working memory. *Acta Psychologica, 79,* 155–170.

Salthouse, T. A. (1992b). *Mechanisms of age–cognition relations in adulthood.* Hillsdale, NJ: Erlbaum.

Salthouse, T. A. (1992c). Reasoning and spatial abilities. In F. I. M. Craik & T. A. Salthouse (Eds.), *Handbook of aging and cognition* (pp. 176–211). Hillsdale, NJ: Erlbaum.

*Salthouse, T. A. (1993). Speed mediation of adult age differences in cognition. *Developmental Psychology, 29,* 722–738.

*Salthouse, T. A. (1994a). Aging associations: Influence of speed on adults age differences in associative learning. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 20,* 1486–1503.

*Salthouse, T. A. (1994b). The nature of the influence of speed on adult age differences in cognition. *Developmental Psychology, 30,* 240–259.

*Salthouse, T. A. (1995a). Differential age-related influences on memory for verbal–symbolic information and visual–spatial information. *Journal of Gerontology: Psychological Sciences, 50B,* P193–P201.

*Salthouse, T. A. (1995b). Influence of processing speed on adult age differences in learning. *Swiss Journal of Psychology, 54,* 102–112.

*Salthouse, T. A. (1996a). General and specific speed mediation of adults age differences in memory. *Journal of Gerontology: Psychological Sciences, 51B,* P30–P42.

Salthouse, T. A. (1996b). The processing-speed theory of adult age differences in cognition. *Psychological Review, 103,* 403–428.

*Salthouse, T. A., & Babcock, R. L. (1991). Decomposing adult age differences in working memory. *Developmental Psychology, 27,* 763–776.

*Salthouse, T. A., Fristoe, N. M., Lineweaver, T. T., & Coon, V. E. (1995). Aging of attention: Does the ability to divide decline? *Memory and Cognition, 23,* 59–71.

*Salthouse, T. A., Fristoe, N. M., & Rhee, S. H. (1996). How localized are age-related effects on neuropsychological measures? *Neuropsychology, 10,* 272–285.

*Salthouse, T. A., Hambrick, D. Z., Lukas, K. E., & Dell, T. C. (1996). Determinants of adult age differences in synthetic work performance. *Journal of Experimental Psychology: Applied, 2,* 305–329.

*Salthouse, T. A., & Hancock, H. E. (1995). *Effects of age and speed on memory as a function of stimulus presentation time.* Unpublished manuscript, Georgia Institute of Technology, School of Psychology, Atlanta.

*Salthouse, T. A., Hancock, H. E., Meinz, E. J., & Hambrick, D. Z. (1996). Interrelations of age, visual acuity, and cognitive functioning. *Journal of Gerontology: Psychological Sciences, 51B,* P317–P330.

*Salthouse, T. A., Kausler, D. H., & Saults, J. S. (1988a). Investigation of student status, background variables, and the feasibility of standard tasks in cognitive aging research. *Psychology and Aging, 3,* 29–37.

Salthouse, T. A., Kausler, D. H., & Saults, J. S. (1988b). Utilization of path analytic procedures to investigate the role of processing resources in cognitive aging. *Psychology and Aging, 3,* 158–166.

*Salthouse, T. A., Letz, R., & Hooisma, J. (1994). Causes and consequences of age-related slowing in speeded substitution performance. *Developmental Neuropsychology, 10,* 203–214.

*Salthouse, T. A., & Meinz, E. J. (1995). Aging, inhibition, working memory, and speed. *Journal of Gerontology: Psychological Sciences, 50B,* P297–P306.

*Salthouse, T. A., & Mitchell, D. R. D. (1990). Effects of age and naturally occurring experience on spatial visualization performance. *Developmental Psychology, 26,* 845–854.

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

*Schaie, K. W. (1989). Perceptual speed in adulthood: Cross-sectional and longitudinal studies. *Psychology and Aging, 4,* 443–453.

Schaie, K. W. (1995). *Adult intellectual development: The Seattle Longitudinal Study.* New York: Cambridge University Press.

*Schludermann, E. H., Schludermann, S. M., Merryman, P. W., & Brown, B. W. (1983). Halstead's studies in the neuropsychology of aging. *Archives of Gerontology and Geriatrics, 2,* 49–172.

Shadish, W. R. (1996). Meta-analysis and the exploration of causal mediating processes: A primer of examples, methods, and issues. *Psychological Methods, 1,* 47–65.

Shipley, W. C. (1940). A self-administering scale for measuring intellectual impairment and deterioration. *Journal of Psychology, 9,* 371–377.

*Stankov, L. (1988). Aging, attention, and intelligence. *Psychology and Aging, 3,* 59–74.

*Stankov, L. (1994). The complexity effect phenomenon is an epiphenomenon of age-related fluid intelligence decline. *Personality and Individual Differences, 16,* 265–288.

*Sterne, D. M. (1973). The Hooper Visual Organization Test and Trail Making Tests as discriminants of brain injury. *Journal of Clinical Psychology, 29,* 212–213.

Talland, G. A. (1968). Age and the span of immediate recall. In G. A. Talland (Ed.), *Human aging and behavior* (pp. 93–129). New York: Academic Press.

*Tamkin, A. S., & Jacobsen, R. (1984). Age-related norms for the Hooper Visual Organization Test. *Journal of Clinical Psychology, 40,* 1459–1463.

Thurstone, L. L. (1938). Primary mental abilities. Chicago: University of Chicago Press.

*Vega, A., & Parsons, O. A. (1967). Cross-validation of the Halstead–Reitan tests for brain damage. *Journal of Consulting Psychology, 31,* 619–625.

Verhaeghen, P., & Marcoen, A. (1993). Memory aging as a general phenomenon: Episodic recall of older adults is a function of episodic recall of young adults. *Psychology and Aging, 8,* 380–388.

Verhaeghen, P., Marcoen, A., & Goossens, L. (1993). Facts and fiction about memory aging: A quantitative integration of research findings. *Journal of Gerontology: Psychological Sciences, 48,* P157–P171.

*Wasserstein, J., Zappulla, R., Rosen, J., & Gerstman, L. (1987). In search of closure: Subjective contour illusions, gestalt completion tests, and implications. *Brain and Cognition, 6,* 1–14.

Wechsler, D. (1958). *Measurement of adult intelligence.* Baltimore: Williams & Wilkins.

*Wilson, T. R. (1963). Flicker fusion frequency, age and intelligence. *Gerontologia, 7,* 200–208.

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