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Little Relation of Adult Age With Cognition After Controlling General Influences

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Both general (i.e., shared across different cognitive measures) and specific (i.e., unique to particular cognitive measures) influences can be postulated to contribute to the relations between adult age and measures of cognitive functioning. Estimates of general and specific influences on measures of memory, speed, reasoning, and spatial visualization were derived in cross-sectional ($N = 5{,}014$) and 3-occasion longitudinal ($N = 1{,}353$) data in adults between 18 and 99 years of age. Increased age was negatively associated with estimates of general influences on cognitive functioning in both the cross-sectional differences and the longitudinal changes. Furthermore, after statistically controlling general influences, the relations of age on the cognitive measures were much smaller than were those in the original measures. Results from these and other analytical procedures converge on the conclusion that adult age appears to have weak relations with specific measures of cognitive functioning, defined as independent of influences shared across different types of cognitive measures, and that this is true in both cross-sectional and longitudinal comparisons. An implication of these findings is that general, as well as domain-specific, influences should be considered when attempting to explain the relations of age on cognitive functioning.

Keywords: aging, cognitive decline, level of analysis

It is sometimes assumed, at least implicitly, that a one-to-one correspondence exists between observed measures and theoretical constructs, such that the measure provides an exhaustive and exclusive assessment of the relevant target construct. However, an alternative perspective is that single assessments are seldom exhaustive, because few constructs are completely represented by a single measure. Furthermore, the association of measures to constructs is rarely exclusive, because nearly all measures have multiple influences. With respect to this latter point, cognitive measures can be postulated to have influences corresponding to unsystematic fluctuation, to the methods and materials involved in the assessment, to the relevant ability construct, and to factors shared with different types of cognitive measures. These latter influences can be designated general because they are common to many cognitive measures.

The most important influences when considering relations of cognitive measures to other variables such as age are not the unsystematic influences, because they are typically considered random measurement error, or the measure-specific influences, because they may be too narrow to have much theoretical significance. Instead, ability-specific and general influences are of greatest interest because depending on their relative contributions, the implications for understanding age–cognition relations could be quite different. That is, if general influences are very small, they could be safely ignored and explanations of cognitive aging phenomena could focus on ability- or domain-specific interpretations. However, if the contribution of general influences is at least moderate, explanations of domain-specific age relations will need to be supplemented with explanations of general age relations to fully account for cognitive aging phenomena. Distinguishing the contributions of general and specific influences on age–cognition relations is therefore an important priority for research in cognitive aging.

The rationale for the current study was that estimates of specific measures of cognitive functioning could be derived by statistically partialing a measure of general influences from the observed scores. A variety of methods have been used in prior studies to estimate general aspects of cognition, ranging from the mean of *z* scores (e.g., Horn, Donaldson, & Engstrom, 1981; Wilson et al., 2009) to the first principal component (PC1) representing the largest proportion of the total variance among measures in a principal components analysis (e.g., Ree & Earles, 1991; Ree, Earles, & Teachout, 1994), to the first principal factor (PF1) representing the largest proportion of shared variance among measures in a principal axis factor analysis (e.g., Karama et al., 2011; Ree & Earles, 1991; Salthouse et al., 2015), to a latent variable defined by variance common to multiple measures (e.g., McArdle & Prescott, 1992; Salthouse & Czaja, 2000; Salthouse, Hambrick, & McGuthry, 1998; Salthouse, Hancock, Meinz, & Hambrick, 1996). Although estimates from the different methods are often highly correlated with one another (e.g., Ree & Earles, 1991), there are important conceptual differences among the methods. For example, estimates based on means and on principal components

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involve all of the variance in the measures, including specific variance in addition to common variance. Only common variance is represented in the general factors based on principal factor analyses and latent variable analyses. However, estimates of the general factor are not available at the level of individual participants with latent variables, and thus the primary analyses in the current study were conducted with the first principal factor (PF1) across all available cognitive measures serving as the estimate of the general factor.

The data were based on participants from the Virginia Cognitive Aging Project, which is an ongoing cross-sectional and longitudinal study focused on cognitive aging (e.g., Salthouse, 2014a; Salthouse, Pink, & Tucker-Drob, 2008). Although measures of vocabulary were also obtained from the participants, they were not included in the current analyses, because they can be considered to represent a different type of cognition (i.e., products of interactions of one's abilities with environmental opportunities and thus an achievement rather than an ability), and they have different age trends from those of other measures of cognition. The focus in the current study was therefore on 12 cognitive measures representing episodic memory (memory), perceptual speed (speed), inductive reasoning (reasoning), and spatial visualization (space) abilities.

Research Goals

Three research goals motivated the current study. These were (a) to determine the relation of age on an estimate of general influences on cognitive functioning, (b) to determine the relation of age on specific measures of cognitive abilities after controlling general influences, and (c) to investigate whether similar patterns of general and specific influences were evident in adults of different ages. Unlike in prior studies, both general and specific estimates of cognitive functioning were derived in cross-sectional and longitudinal data and in adults ranging from 18 to 99 years of age. On the basis of prior research with different types of analytical procedures (e.g., Salthouse & Czaja, 2000; Salthouse & Ferrer-Caja, 2003; Salthouse et al., 2008; Tucker-Drob, 2011a), general influences on cognitive functioning were expected to be strongly related to age, specific influences were expected to have relatively small relations with age, and the contributions of general and specific influences were postulated to be roughly comparable throughout adulthood. However, it is important to note that even if these expectations were not supported, the results will be informative about the roles of general and specific influences on adult age differences and changes in cognitive functioning.

Method

Participants

Characteristics of the participants, who were recruited from advertisements and referrals from other participants, are summarized in Table 1. It can be seen that the participants averaged over 15 years of education and that their self-rated health was in the good to very good range. The high average years of education and the average estimated IQ of about .6 standard deviations above the mean of a nationally representative normative sample indicate that the participants can be considered to be high functioning relative to the general population.

The longitudinal participants were a subset of the cross-sectional sample. Only participants who had completed at least three occasions were included in the longitudinal sample to ensure that the general factor was based on the same participants at each occasion. Inspection of Table 1 reveals that individuals 40 years and older in the longitudinal sample had more years of education and higher

Table 1
Demographic Characteristics of Cross-Sectional and Three-Occasion Longitudinal Participants

Variable	Age group								*r*
	All	20s	30s	40s	50s	60s	70s	80s+	
				Cross-sectional					
N	5,014	883	501	779	1144	883	560	264	
Age in years: *M* (*SD*)	50.9 (18.2)	23.1	34.3	45.0	54.4	64.1	74.2	84.0	
Proportion female	.65	.58	.69	.71	.70	.66	.58	.50	−.01
Health[a]: *M* (*SD*)	2.2 (.9)	2.0	2.1	2.2	2.2	2.1	2.4	2.6	.13*
Educ. in years: *M* (*SD*)	15.5 (3.9)	14.7	15.7	15.3	15.7	16.4	15.9	16.1	.17*
Est. IQ[b]: *M* (*SD*)	109.3 (14.3)	109.1	107.6	108.5	109.8	112.0	109.9	104.9	.01
				Longitudinal					
N	1,353	110	102	259	379	301	165	37	
Age in years: *M* (*SD*)	54.0 (15.0)	23.0	35.0	45.3	54.4	64.2	74.0	83.1	
Proportion female	.68	.62	.76	.71	.74	.67	.59	.49	−.05
Health[a]: *M* (*SD*)	2.2 (.9)	2.0	2.4	2.1	2.1	2.1	2.3	2.5	.04
Educ. in years: *M* (*SD*)	15.8 (2.7)	14.1	15.3	15.4	16.1	16.5	16.1	16.5	.21*
Est. IQ[b]: *M* (*SD*)	112.1 (14.0)	106.3	107.3	111.2	114.1	114.1	112.6	110.2	.12*
T1–T2 interval in years (*SD*)	2.8 (1.3)	2.7	2.7	3.1	2.7	2.7	2.5	2.3	−.08*
T2–T3 interval in years (*SD*)	3.1 (1.4)	3.1	3.4	3.3	3.1	2.9	3.1	3.0	−.07

Note. Educ. = education; Est. = estimated; T in T1–T3 = time.
[a] Health was self-rated on a scale ranging from 1 (*excellent*) to 5 (*poor*). [b] Estimated IQ is an estimate of IQ based on age-adjusted scores on three tests (i.e., Shipley Abstraction, Paper Folding, and Antonym Vocabulary) found to be highly related to the Wechsler Adult Intelligence Scale—Fourth Edition full-scale IQ (Salthouse, 2014b).

estimated IQs than did their age peers in the initial sample, which is probably attributable to greater attrition of the lowest performing participants in this age range. The interval between occasions ranged from less than 1 year to 12 years, with averages of 2.8 years for the interval from the first (Time 1 [T1]) to the second (T2) occasion and 3.1 years for the interval from the second (T2) to the third (T3) occasion.

Cognitive Measures

Episodic memory was assessed with the Logical Memory test (Wechsler, 1997b), the Word List test (Wechsler, 1997b), and a locally developed Paired Associates test (Salthouse, Fristoe, & Rhee, 1996). Speed was measured with Digit Symbol (Wechsler, 1997a), Letter Comparison (Salthouse & Babcock, 1991), and Pattern Comparison (Salthouse & Babcock, 1991) tests. Reasoning was assessed with the Raven's Advanced Progressive Matrices (Raven, 1962), Shipley Abstraction (Zachary, 1986), and Letter Sets (Ekstrom, French, Harman, & Dermen, 1976) tests. Spatial visualization was assessed with the Spatial Relations test from the Differential Aptitude Test Battery (Bennett, Seashore, & Wesman, 1997), the Paper Folding test (Ekstrom et al., 1976), and the Form Boards test (Ekstrom et al., 1976). Additional information about the measures, including reliability and validity (in the form of loadings of the measures on relevant ability factors), is contained in other publications (e.g., Salthouse, 2014a; Salthouse et al., 2008).

Analyses

Comparisons across tests and abilities were facilitated by converting all test scores to *z* score units on the basis of the means and standard deviations of the scores on the first occasion. As noted earlier, the estimate of the general cognitive factor was the unrotated first principal factor (PF1) obtained from a principal axis factor analysis conducted on the 12 cognitive measures. Separate factor analyses were conducted on the 12 measures in the cross-sectional sample and on the data from each of the three occasions in the longitudinal sample. In order to ensure that PF1 values were available for each participant, I replaced missing values by the measure mean when computing the PF1 values.

Composite scores were created for each cognitive ability by averaging the mean *z* scores for the three tests postulated to represent a given ability. A second domain-specific composite score was created for each ability by regressing the influence of the general factor (i.e., PF1) from each *z* score before averaging the three relevant scores to form the composite.

The longitudinal data were analyzed with latent growth curve models (e.g., Anstey, Hofer, & Luszcz, 2003; T. E. Duncan, Duncan, Strycker, Li, & Alpert, 1999) conducted with the AMOS (Arbuckle, 2013) structural equation modeling program. A latent level variable was defined by equal loadings of the composite scores on the three occasions, and a latent change variable was defined by loadings of 0, .5, and 1.0 on the composite scores at the first, second, and third occasions, respectively. With these specifications, the level parameter corresponds to the average performance across the three occasions and the change parameter corresponds to the difference in performance across successive occasions. Influences associated with age were evaluated with the unstandardized coefficient relating age to the latent level and latent change variables.

Two fit indices were examined to assess the fits of the latent growth curve models. The comparative fit index (CFI) compares the fit of a target model to the fit of a model in which the variables are assumed to be uncorrelated, and the root-mean-square error of approximation (RMSEA) is the square root of the mean of the differences between corresponding elements of the observed and predicted covariance matrix. CFI values above about .95 and RMSEA values less than about .08 are considered to represent good fit (e.g., Kline, 2005). All of the latent growth curve models had excellent fits, with CFI values ranging from .99 to 1.00 and RMSEA values ranging from .00 to .06.

Because many of the earlier studies investigating longitudinal change have included only older adults (e.g., Anstey et al., 2003; Habib, Nyberg, & Nilsson, 2007; Lindenberger & Baltes, 1994; Tucker-Drob, 2011b; Tucker-Drob, Johnson, & Jones, 2009), relatively little is known about the composition of cognitive change in young and middle-aged adults. Additional analyses were therefore conducted on subsamples of participants under and over 60 years of age to examine the patterns of general and specific influences at different periods in adulthood.

Results

Principal Factor Analyses

Two types of analyses were conducted to investigate the composition of the PF1 general factor. One type consisted of the computation of congruence coefficients to evaluate the similarity of the loading patterns in the cross-sectional data and in the data at each longitudinal occasion. All of the congruence coefficients were above .99, which indicates that there was a very similar pattern of PF1 loadings in each set of data.

A second set of analyses investigated the relation of age on the composition of the PF1 factor in the cross-sectional data and at each occasion in the longitudinal data. The analyses consisted of predicting each cognitive measure from the relevant PF1, age, and their interaction. Of particular interest was the interaction of age and PF1 because it indicated whether the PF1 influence on the cognitive measures varied as a function of age. Table 2 contains the R^2 values for PF1, age, and their interaction in these analyses. Inspection of the values in the first column reveals that the matrix reasoning measure (Raven's Advanced Progressive Matrices) had the strongest relations with the general factor and that the memory and speed measures had the weakest relations. Several of the Age × PF1 interactions on individual cognitive measures were significant ($p < .01$), but all were associated with small proportions of variance compared to that associated with PF1 and with age. These results suggest that the composition of the PF1 estimate of the general influences was fairly similar across adulthood.

Means (and standard errors) of the PF1 values are portrayed in Figure 1 as a function of age in 5-year bins for the large cross-sectional sample and in 10-year bins for the smaller longitudinal sample. It can be seen that there was a monotonic decline with increased age in the cross-sectional data and across-occasion increases at young ages shifting to decreases at older ages in the longitudinal data.

Table 2
R^2 Associated With Prediction of Cognitive Measures in Adults in Cross-Sectional Data and on Three Occasions in Longitudinal Data

Cognitive measure	PF1	Age	PF1 × Age
Word Recall			
Cross-sectional	.47*	.18*	.01*
Longitudinal (T1)	.36*	.08*	.00
Longitudinal (T2)	.40*	.12*	.00
Longitudinal (T3)	.46*	.16*	.01*
Paired Associates			
Cross-sectional	.46*	.14*	.00
Longitudinal (T1)	.39*	.07*	.00
Longitudinal (T2)	.47*	.11*	.00
Longitudinal (T3)	.50*	.14*	.00
Logical Memory			
Cross-sectional	.39*	.06*	.00
Longitudinal (T1)	.29*	.01*	.00
Longitudinal (T2)	.39*	.05*	.00
Longitudinal (T3)	.42*	.06*	.00
Digit Symbol			
Cross-sectional	.54*	.31*	.00*
Longitudinal (T1)	.44*	.21*	.00*
Longitudinal (T2)	.47*	.26*	.00*
Longitudinal (T3)	.55*	.29*	.00
Pattern Comparison			
Cross-sectional	.44*	.31*	.00
Longitudinal (T1)	.33*	.20*	.00
Longitudinal (T2)	.34*	.21*	.00
Longitudinal (T3)	.39*	.24*	.00
Letter Comparison			
Cross-sectional	.43*	.23*	.01*
Longitudinal (T1)	.30*	.15*	.01*
Longitudinal (T2)	.28*	.17*	.00*
Longitudinal (T3)	.38*	.21*	.00*
Matrix Reasoning			
Cross-sectional	.75*	.25*	.00*
Longitudinal (T1)	.72*	.13*	.00
Longitudinal (T2)	.74*	.14*	.00
Longitudinal (T3)	.74*	.17*	.00
Shipley Abstraction			
Cross-sectional	.71*	.14*	.01*
Longitudinal (T1)	.68*	.05*	.00*
Longitudinal (T2)	.71*	.08*	.00*
Longitudinal (T3)	.71*	.11*	.01*
Letter Sets			
Cross-sectional	.53*	.07*	.01*
Longitudinal (T1)	.50*	.02*	.00*
Longitudinal (T2)	.49*	.02*	.01*
Longitudinal (T3)	.50*	.03*	.00*
Spatial Relations			
Cross-sectional	.56*	.11*	.01*
Longitudinal (T1)	.56*	.03*	.00*
Longitudinal (T2)	.59*	.04*	.00*
Longitudinal (T3)	.56*	.05*	.00*
Paper Folding			
Cross-sectional	.58*	.16*	.01*
Longitudinal (T1)	.54*	.05*	.00*
Longitudinal (T2)	.54*	.09*	.00*
Longitudinal (T3)	.58*	.11*	.00*
Form Boards			
Cross-sectional	.49*	.19*	.01*
Longitudinal (T1)	.41*	.08*	.01*
Longitudinal (T2)	.45*	.13*	.01*
Longitudinal (T3)	.50*	.17*	.01*

Note. The R^2 values for PF1 and age were obtained when the predictors were considered alone, and that for the PF1 × Age interaction was obtained when all three predictors were considered simultaneously. PF1 = first principal factor; T in T1–T3 = time.
* $p < .01$.

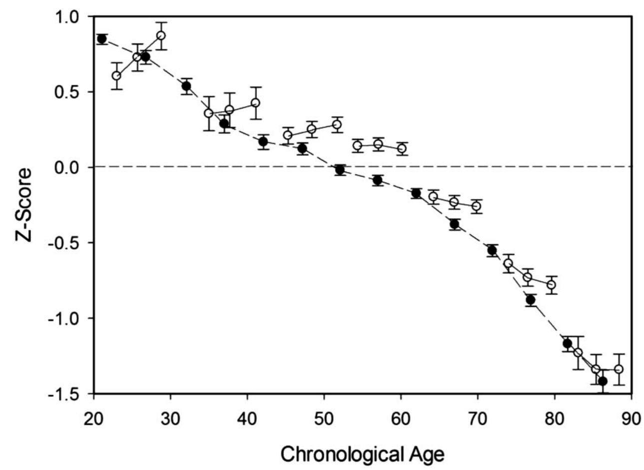

Figure 1. Means (and standard errors represented by error bars) of the first principal factor estimate of the general factor as a function of age in the cross-sectional sample (solid symbols) and on the three occasions in the longitudinal sample (open symbols). Because the cross-sectional sample was much larger than the longitudinal sample, 5-year age bins were used in the cross-sectional sample and 10-year age bins for the longitudinal sample. The dashed line represents the cross-sectional trends.

The correlation of age and PF1 was −.56 in the cross-sectional sample, and the age–PF1 correlations in the longitudinal sample were −.40 at T1, −.45 at T2, and −.50 at T3. The correlations were more negative on later occasions because, as portrayed in Figure 1, there were increases across occasions at young ages and decreases at older ages.

Cross-Sectional Relations

Regression analyses were conducted to investigate the relation of age with the PF1 values postulated to represent a general factor and with the original and specific (i.e., PF1-partialed) composite scores. Unstandardized coefficients for the linear age relations on the PF1 scores, as well as on the composite scores before and after partialing the influence of the general factor from each of the cognitive measures, are presented in the top panel of Table 3.

The coefficient of −.030 for PF1 in the first row of Table 3 is consistent with the pattern in Figure 1, where the PF1 values differed by about 1.5 standard deviation units across a 50-year interval. The negative regression coefficients in the other rows in the top panel of Table 3 indicate that increased age was associated with lower performance on each of the composite scores. Of importance, the age relations on the composite scores were considerably reduced after controlling the estimate of the general cognitive factor in each ability domain. Because general influences shared with other cognitive measures have been partialed from these residual scores, they can be postulated to represent domain-specific influences. The finding that the age relations on the estimates of specific influences were much smaller than those on the original observed scores implies that large proportions of the age-related effects in each ability domain were shared and were not independent of effects on other cognitive measures.

The patterns of large negative age relations in the original scores and little or no age domain-specific relations after control of the

Table 3
Unstandardized Regression Coefficients in Cross-Sectional and Longitudinal Comparisons on the Estimate of the General Factor (PF1) and on Composite Scores Representing Four Cognitive Abilities

	Total sample		Age 18–59		Age 60–99	
Ability	Orig	Orig.G	Orig	Orig.G	Orig	Orig.G
			Cross-sectional[a]			
PF1	−.030*		−.027*		−.051*	
Memory	−.019*	.001	−.015*	.003*	−.043*	−.009*
Speed	−.029*	−.008*	−.023*	−.004*	−.045*	−.008*
Reasoning	−.022*	.003*	−.018*	.004*	−.046*	−.003
Space	−.022*	−.002*	−.024*	−.003*	−.029*	.010*
			Longitudinal—level[a]			
PF1	−.025*		−.015*		−.054*	
Memory	−.014*	.001	−.006*	.002	−.033*	−.002
Speed	−.026*	−.011*	−.016*	−.008*	−.040*	−.011*
Reasoning	−.015*	.005*	−.005	.006*	−.039*	.002
Space	−.014*	.003*	−.011*	−.001	−.033*	.006
			Longitudinal—change[b]			
PF1	−.007*		−.008*		−.004	
Memory	−.009*	−.001	−.006*	.001	−.017*	−.008
Speed	−.006*	.001	−.008*	−.001	−.005	.002
Reasoning	−.006*	.000	−.006*	.000	−.009*	−.003
Space	−.007*	−.001	−.007*	.000	−.005	.001

Note. Orig refers to analyses without controlling the general factor; Orig.G refers to analyses after partialing the influence of the general factor from the observed test scores. PF1 = first principal factor.
[a] Coefficients are in standard deviation units per year of age. [b] Coefficients are in standard deviation units per longitudinal occasion.
* $p < .01$.

general factor are also apparent in the four panels of Figure 2. Observed composite scores in this figure are represented by solid symbols, and the domain-specific composite scores (created after statistically controlling the PF1 variation) are represented by open symbols. Notice that there were strong negative age trends in the lines connecting the solid symbols but that the lines connecting the open symbols, corresponding to specific influences, were nearly flat, with little or no relation to age.

In order to determine whether the results varied according to age, the analyses were repeated for subsamples under (N = 3,307) and over (N = 1,707) 60 years of age. The results of these additional analyses are presented in the rightmost four columns in Table 3, where it can be seen that the age relations were more negative in the over-60 group than in the under-60 group in the PF1 measure and in the composite scores in each ability except space. As in the analyses in the total sample, however, the age relations in the composite scores after controlling the general influence were substantially reduced in both age groups, implying relatively small relations of age on domain-specific influences.

Longitudinal Relations

Unstandardized coefficients for the relations of age on the level and change parameters derived from the latent growth models are reported in the bottom two panels of Table 3. It can be seen that there were significant negative age relations on both the level and change parameters with the PF1 estimate of the general factor and with the observed composite scores in each ability domain. In addition, partialing the estimates of the general factor from the composite cognitive measures at each occasion resulted in weak negative or slightly positive relations of age with the level parameter in all abilities and in the elimination of all of the significant relations of age with the change parameter. The small positive relations on the reasoning measures may reflect an overcorrection of general influences because the values in the first column of Table 2 indicate that these measures had very high relations with the PF1 estimates of the general factor.

Means (and standard errors) of the composite scores representing each cognitive ability are portrayed as a function of longitudinal occasion and age decade in the four panels of Figure 3. As in Figure 2, the observed composite scores are represented by solid symbols, and the specific composite scores (created by removing the occasion-specific PF1) are represented by open symbols. Notice that in the observed scores increased age was associated with more-negative values at each occasion and with more-negative across-occasion slopes. However, both of these age relations were greatly attenuated after adjusting for general influences.

As with the cross-sectional data, the analyses were repeated for subsamples under (N = 850) and over (N = 503) 60 years of age. The results in the bottom right columns of Table 3 indicate that the age–level relations were more negative in the older group than in the younger group but that the age–change relations were generally similar in both groups. Of particular interest was the finding that statistical control of the general influences substantially reduced the age relations in the level and change parameters in both age groups and that there were no significant relations of age on the change in estimates of domain-specific influences.

Robustness Analyses

In order to examine the robustness of the results, additional analyses were conducted with cognitive functioning represented by scores on individual measures or on latent variables instead of composite scores and with the estimate of the general cognitive factor based on the mean of the z scores or by a single latent variable instead of the PF1 value. Furthermore, to determine whether the attenuation of the age relations after partialing the influence of the general factor might have been attributable to inclusion of target measures (i.e., the dependent measures of primary interest in the analyses) in the estimate of the general factor, all of the analyses were repeated after excluding measures of the target ability when deriving the PF1. For example, the general factor when analyzing memory ability was based on the scores on the three speed tests, the three reasoning tests, and the three space tests but not the three memory tests. Finally, in order to determine whether the age trends were affected by age differences in other variables, the analyses were repeated with covariates consisting of self-rated health, years of education, estimated IQ, and length of the T1–T2 and T2–T3 intervals in the longitudinal data. In each case, the results of these additional analyses closely resembled those in Table 3 and in Figures 2 and 3, with substantial negative age relations on the general factor but small age relations on the hypothesized specific aspects of the cognitive measures created by controlling influences of the general factor.

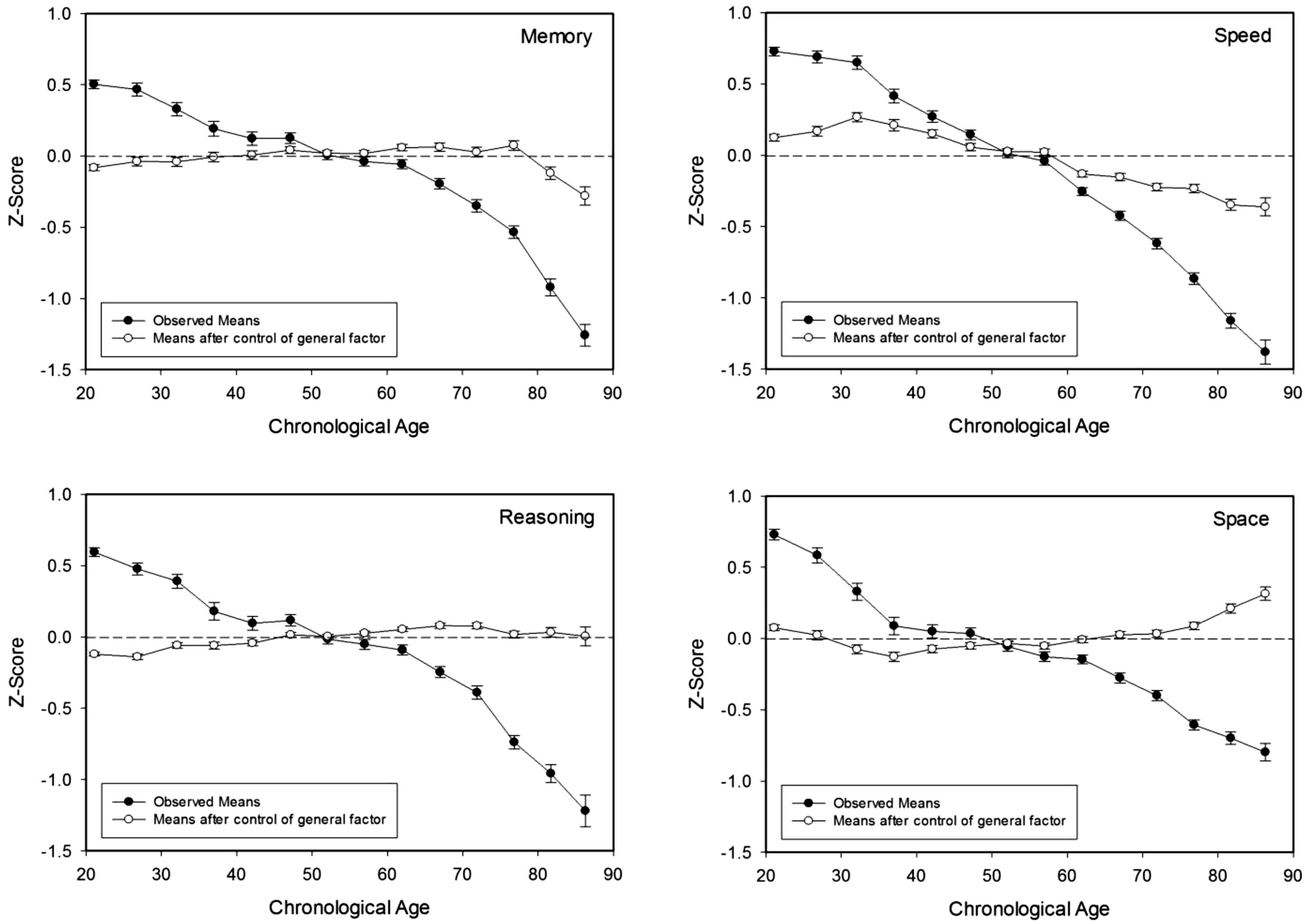

Figure 2. Means (and standard errors represented by error bars) of composite scores before and after control of an estimate (first principal factor) of the general factor. Dashed lines represent a z-score of 0.

Discussion

Three research questions motivated the current study. The first question concerned the relation between age and general cognitive functioning, defined as influences on cognition common to different types of cognitive measures. Because they are based on the variance shared among 12 different cognitive tests and because the values are associated with small standard errors, the results in Figure 1 can be considered to provide a relatively precise characterization of general age-related influences in cross-sectional and longitudinal comparisons of cognitive functioning. The patterns in the figure, together with the results reported in Table 3, indicate that increased age was associated with lower levels of the general factor, particularly at older ages, where the negative age relations were more pronounced. In addition, increased age was associated with more-negative longitudinal change in the general factor, because the across-occasion change was positive at young ages and negative at older ages.

The second research question concerned the relation between age and specific measures of cognitive functioning. Estimates of specific cognitive measures were based on the assumption that observed scores reflect a mixture of general and specific influences and hence that specific scores can be obtained by statistically partialing an estimate of general influences from the observed scores. The results in Table 3 and in Figures 2 and 3 indicate that although there were strong negative cross-sectional and longitudinal age relations in the observed scores, the age relations were much smaller in both types of data when the PF1 estimate of the general factor was statistically partialed from the target measures to yield estimates of specific influences.

Some variation was evident across cognitive ability domains. To illustrate, the small age relations on the reasoning and space measures when general influences were controlled implies that most of the age–level and nearly all of the age–change relations on the reasoning and space measures were general rather than domain-specific. However, the existence of significant age relations on speed measures after controlling general influences implies that some of the age–speed relations in the cross-sectional analyses and in the level parameter in the longitudinal analyses were independent of the general factor. In addition, the significant age–memory relations after controlling general influences in adults over 60 suggests that specific influences were operating on memory ability at older ages in the cross-sectional data. The determi-

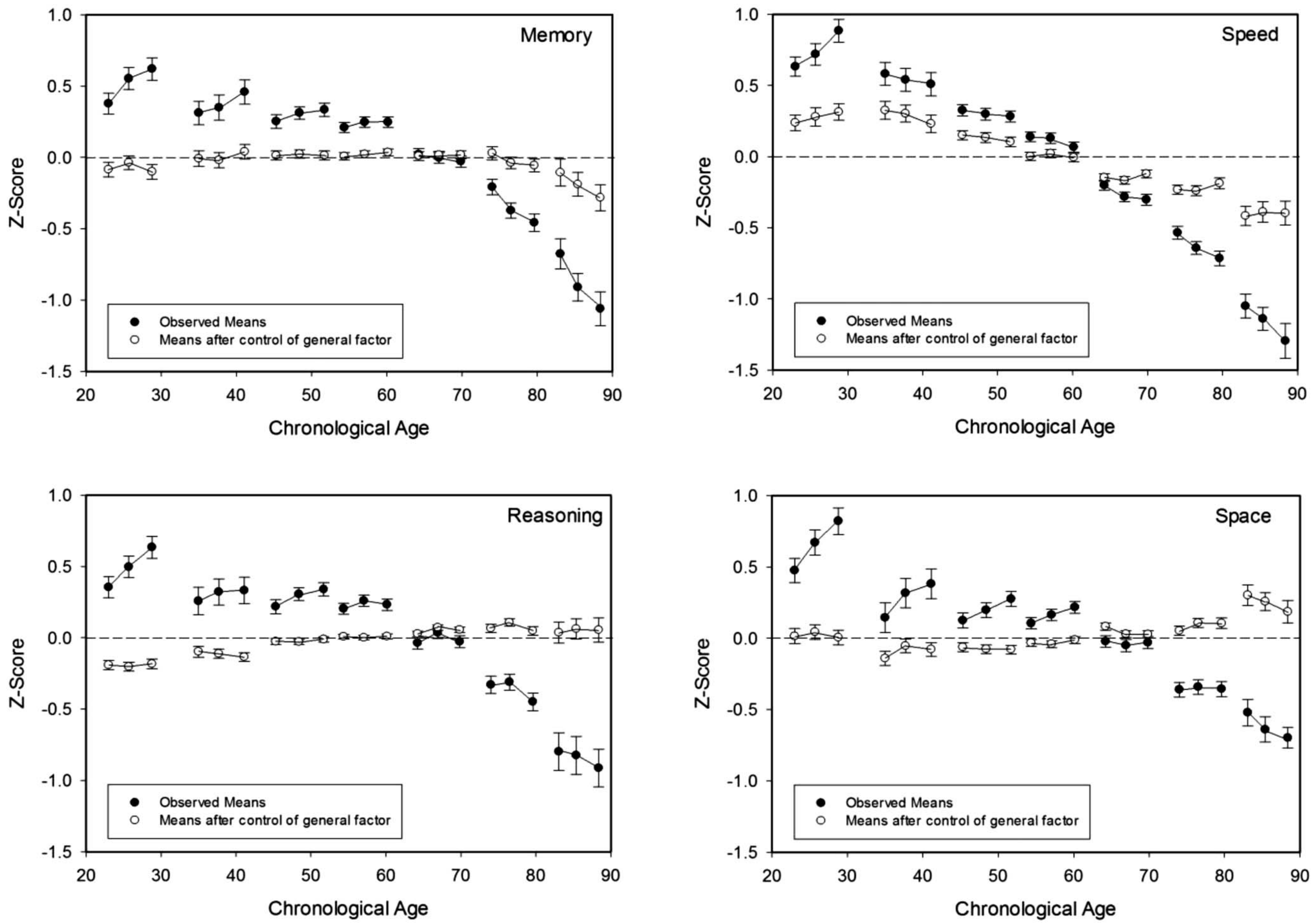

Figure 3. Means (and standard errors represented by error bars) of composite scores on each longitudinal occasion before and after control of an estimate (first principal factor) of the general factor at each occasion. Dashed lines represent a z-score of zero.

nants of the specific influences in speed and memory could be quite different, but in both cases the results suggest that the age-related effects in speed and memory represent a mixture of general and domain-specific influences.

The third major question of interest in the study was whether similar patterns of general and specific influences on cognitive functioning were operating across different periods in adulthood. Two sets of results are relevant to this question. One set consists of the interactions of age and PF1 in the prediction of the cognitive measures because they indicate whether the influence of the general factor on individual cognitive measures varied with age. Several of the interactions in Table 2 were significantly different from zero, but all were associated with small proportions of variance relative to those associated with the main effects of PF1 and age. The small interactions imply that there were nearly comparable contributions of general influences on the cognitive measures at different periods in adulthood.

The second set of results are the age relations in the observed scores before and after controlling the general influence in subsamples of participants under and over 60 years of age. Inspection of the values in Table 3 reveals that there were similar patterns of small age relations after control of the PF1 variance in the cross-sectional, as well as longitudinal-level and longitudinal-change, values in both age groups. Despite the more-negative age relations at older ages, therefore, relatively small specific and substantial general influences appear to be operating in adults under and over 60 years of age.

The longitudinal age relations differed from the cross-sectional relations in exhibiting increases rather than decreases in the average score among adults younger than about 50 years of age. Previous research comparing the performance of individuals tested for the first time when longitudinal participants were tested for the second time has suggested that the across-occasion increases among young and middle-aged adults in longitudinal comparisons likely reflect positive effects of prior testing experience (e.g., Salthouse, 2014c, 2015). Furthermore, two related findings suggest that test experience effects in the longitudinal comparisons were primarily attributable to general influences. The first is the presence of across-occasion increases in the estimates of the general influences in Figure 1, and the second is the absence of across-occasion increases in the specific measures in Figure 3 after partialing general influences from the observed scores. The former results imply the existence of experience effects in the general estimates, and the latter results imply the lack of experience effects in the specific estimates. The conclusion that test experience effects are largely attributable to general influences is consistent with a recent finding of significant correlations among estimates of test experience effects based on different cognitive measures (Salthouse, 2015).

The analytical method used in this study was based on the assumption that general influences on the measures could be statistically removed by partialing the unrotated first principal factor derived from the observed scores. To the extent that this assumption is valid, at least two types of age-related influences can be postulated to be operating on cognitive measures: general influences shared across different types of cognitive measures, with age trends approximated by the functions in Figure 1, and specific influences restricted to particular cognitive tests and abilities, with age trends approximated by the open symbols in Figures 2 and 3. It is important to note that the results in these figures suggest that most of the relations of age on cognitive functioning in this study were attributable to general rather than to domain-specific influences.

A substantial involvement of general (or shared) influences on cross-sectional age–cognition relations has also been documented in a number of previous studies using a variety of different analytical methods. For example, estimates of the general influence have been based on the highest level in a hierarchical structure (e.g., Lindenberger & Baltes, 1994; Salthouse & Ferrer-Caja, 2003), on an orthogonal general factor in a bifactor structure (e.g., Booth et al., 2013; Hildebrandt, Wilhelm, Schmiedek, Herzmann, & Sommer, 2011; Salthouse & Ferrer-Caja, 2003; Schmiedek & Li, 2004), and on a latent variable defined by the variance common to all measures (e.g., Salthouse, 1998; Salthouse & Czaja, 2000; Salthouse et al., 1998; Salthouse, Hancock, et al., 1996). In each of these studies, the relations of age on individual cognitive measures or on aggregated ability measures were substantially reduced after controlling the influence of the general factor.

The primary method used to investigate general influences in longitudinal studies has been based on inspection of correlations among longitudinal changes in measures representing different cognitive abilities. Consistent with the existence of a general influence on cognitive change, significant correlations of changes in different cognitive measures have been reported in numerous studies (e.g., Anstey et al., 2003; Habib et al., 2007; Salthouse, 2010a, 2010b; Zelinski & Stewart, 1998; Zimprich & Martin, 2002). Moreover, in several of the studies the results were interpreted as evidence for a general change factor (e.g., Ghisletta, Rabbitt, Lunn, & Lindenberger, 2012; Hertzog, Dixon, Hultsch, & MacDonald, 2003; Hultsch, Hertzog, Small, & Dixon, 1999; Lindenberger & Ghisletta, 2009; Reynolds, Gatz, & Pedersen, 2002; Tucker-Drob, 2011a, 2011b; Tucker-Drob et al., 2009; Tucker-Drob, Briley, Starr, & Deary, 2014; Tucker-Drob, Reynolds, Finkel, & Pedersen, 2014; Wilson et al., 2002; Yam, Gross, Prindle, & Marsiske, 2014).

The current study extends previous results by using the same analytical procedure to investigate general and specific influences in both cross-sectional and longitudinal comparisons. That is, estimates of general influences were statistically partialed from the cross-sectional scores and from the longitudinal scores at each occasion to yield estimates of specific influences. The results in Table 3 and in Figures 2 and 3 indicate that the age–cognition relations in both types of data were greatly reduced after controlling general influences, implying that there is little relation of age on specific measures of cognition.

Results of these and other studies therefore suggest that large proportions of the age-related effects on cognitive functioning are general and are shared with other cognitive measures and are not specific and unique to a particular measure or ability. The findings also imply that researchers investigating age differences or changes in a particular cognitive measure may have been inadvertently examining relations of age on general influences shared with many different types of cognitive measures and not simply specific relations of age on the cognitive measure of primary interest. Interpretations of the nature and causes of adult age differences in particular cognitive measures may therefore be misleading unless shared and unique influences are distinguished. Whether this is also true in the period of child development remains to be determined.

In light of the compelling evidence for general influences on age–cognition relations in this and earlier studies, an important goal for future research is to specify the nature of the general factor. At least three possible substrates of general aspects of cognition can be identified on the basis of recent neurobiological research. That is, some researchers have postulated that the dorsal lateral prefrontal cortex is a critical region responsible for coordination of processes involved in different cognitive measures (e.g., J. Duncan et al., 2000; Gray, Chabris, & Braver 2003), others have proposed that general factors in cognition are associated with a distributed network of brain regions (e.g., Barbey et al., 2012; Gläscher et al., 2010; Jung & Haier, 2007), and still others have reported that measures of structural and functional connectivity among different brain regions are associated with influences shared across different cognitive measures (e.g., Booth et al., 2013; Cole, Yarkoni, Repovs, Anticevic, & Braver, 2012).

A potentially productive strategy to investigate the involvement of these or other neurobiological measures in general age-related influences is to incorporate them into analyses similar to those reported earlier. That is, the relevant neurobiological measures could replace the PF1 estimate of the general factor to determine whether these measures (a) had strong correlations with the general cognitive factor; (b) exhibited negative relations with age similar to those in Figure 1; and (c) resulted in reduced age–cognition relations when influences of the neurobiological measures were partialed from the target cognitive measures, analogous to the findings reported in Figures 2 and 3. If each of these conditions were met, the neurobiological measures might be considered plausible substrates for the general factor postulated to be involved in negative relations between age and cognitive functioning. Research of this type will be expensive and time-consuming because neuroimaging data will be required from a moderately large number of adults across a wide age range who have each performed a battery of different types of cognitive tests. Nevertheless, efforts such as this could be extremely informative in characterizing the neurobiological bases of the general cognitive factors associated with substantial proportions of the age–cognition relations.

Several limitations of the study should be noted. First, most of the participants were healthy, high-functioning adults, and it is possible that the relative contributions of general and specific influences are different in lower functioning adults or in those with disease or pathology. Second, the longitudinal interval in the study was relatively short, with an average of less than about 6 years between the first and third occasions, and the relative contributions of general and specific influences could be different at longer intervals. And third, although four ability domains were examined, different patterns of general and domain-specific influences might be evident with other ability domains.

However, it is also important to recognize strengths of the current study. For example, the sample of research participants was moderately large in both the cross-sectional and longitudinal comparisons, and the age range spanned most of adulthood. Furthermore, sensitivity and breadth of assessment were enhanced by the availability of multiple measures from multiple cognitive domains. And finally, very similar patterns were evident across different analytical methods, and thus the results can be inferred to be robust.

To summarize, results from a variety of analytical methods and different combinations of cognitive measures converge on the conclusion that there are strong general or domain-independent influences, in addition to more-modest specific influences, contributing to both the cross-sectional and longitudinal relations between age and measures of cognitive functioning. Interpretations of the relations of age on cognitive measures should therefore incorporate explanations of influences that are common to many different cognitive measures and not restrict explanations to influences that are specific to the measures of primary interest.

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