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Does the Level at Which Cognitive Change Occurs Change With Age?

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Abstract

Increased age in adulthood is associated with systematically more negative cognitive change, but relatively little is known about the nature of change at different ages. The present study capitalized on the hierarchical structure of cognitive abilities to investigate possible age differences in the level at which change operates. Reductions in the longitudinal associations between test scores when across-time relations were specified at different levels in the hierarchical structure were used to infer contributions to change from the level of abilities and from the level of a general factor. Although the pattern of influences varied across different cognitive abilities, the results revealed little or no age differences in the relative contributions to change from different levels in the hierarchy.

Keywords

aging, cognitive ability, intelligence

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It is well established that cognitive variables can be organized into a hierarchical structure with measured variables at the lowest level and progressively broader abilities located at successively higher levels in the hierarchy (e.g., Deary, Penke, & Johnson, 2010; Gustafsson, 1988; Salthouse, 2004). Moreover, when longitudinal data are available, a hierarchical structure can be constructed for each measurement occasion, and relations between occasions can be examined at different positions in the hierarchy to investigate the levels at which cognitive changes occur. If data are available from adults of different ages, it is also possible to determine if there are age differences in the relative influences on change from different levels. That is, one can ask whether change operates primarily at the level of specific individual variables, the level of a first-order cognitive ability, or the level of a higher-order general (*g*) factor, and whether the relative influences on change from these levels vary as a function of age.

One can distinguish at least three perspectives regarding possible age-related shifts in the level at which cognitive change operates. One is the dedifferentiation hypothesis, which postulates that cognitive variables and abilities become less distinct (less differentiated) with increased age. Evidence for the dedifferentiation hypothesis is currently mixed; some positive findings have been reported (e.g., de Frias, Lovden, Lindenberger, & Nilsson, 2007; Ghisletta & de Ribaupierre, 2005; Ghisletta & Lindenberger, 2003), but several studies did not find stronger correlations between cognitive abilities among older individuals (e.g., Anstey, Hofer, & Luszcz, 2003; Tucker-Drob & Salthouse, 2008; Zelinski & Lewis, 2003), particularly when ability dedifferentiation (i.e., higher correlations at lower ability levels) was distinguished from age dedifferentiation (e.g., Batterham, Christensen, & Mackinnon, in press; Tucker-Drob, 2009). Despite its equivocal status, the dedifferentiation hypothesis clearly predicts that changes in different cognitive variables should be more highly intercorrelated with advancing age, such that higher-order factors' influences on change should increase with age.

An alternative view might be termed disintegration, in that cognitive variables could be postulated to become more, rather than less, independent of one another with increasing age. That is, age-related decreases in structural or functional connectivity (e.g., O'Sullivan et al., 2001; St. Jacques, Dolcos, & Cabeza, 2009) could lead to weaker interrelations among cognitive variables, which in turn could lead to age-related decreases in influences on change from higher levels in the ability structure.

Still another possibility is that increased age is associated with more negative cognitive change without appreciable shifts in the level at which cognitive change operates (the equivalent-structural-influences hypothesis). A key assumption of this perspective is that the factors responsible for relations between age and change are more quantitative than qualitative, and hence this perspective predicts little or no relation between age and the level at which change operates.

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In the current study, the level at which change operates was inferred by examining the covariance (a measure of the relation between variables, which in its standardized form is the correlation coefficient) for a given test score between two measurement occasions, T1 and T2, as schematically illustrated in Figure 1. The top panel of the figure portrays the covariance between the residuals of the target test score at these two points in time. This covariance indicates the total overlap in the scores across the two occasions, and is composed of covariance unique to the test scores and covariance shared with higher-level factors. The middle panel portrays the covariance between the same test scores after specifying an influence from T1 to T2 at the ability level, and the third panel illustrates the covariance between the same test scores after specifying an influence from T1 to T2 at the highest level in the hierarchy. The assumption underlying this study's approach is that the degree to which the across-occasion covariance for a particular test score is reduced after specifying these higher-order relations can be used as an indication of the magnitude of the influence from T1 to T2 at those higher levels.

For example, assume that the covariance across the T1 and T2 measurement occasions for a particular test score when considered in isolation is 10, that the covariance is 2 when a relation between T1 and T2 is specified at the ability level, and that it is 4 when a relation between T1 and T2 is specified at the highest, *g*, level. Given this pattern of results, 80% ([10 – 2]/10) of the longitudinal change in the test score could be inferred to operate at or above the ability level, and 60% ([10 – 4]/10) could be inferred to operate at the *g*-factor level. Stated somewhat differently, 20% of the variance in change could be inferred to be specific to the test score, 20% could be inferred to operate at the ability level, and 60% could be inferred to operate at the level of the *g* factor.

Because the sample in the current study was moderately large, separate analyses were conducted for adults in each age decade from the 20s through the 80s. Age differences in the magnitude of the T1-T2 relations at the various levels in the hierarchical structure are relevant to the possibility of age-related shifts in the level at which cognitive change operates. That is, a shift to more general influences with increased age would support the dedifferentiation hypothesis, a decrease in higher-level influences with increased age would support the disintegration hypothesis, and near-constancy across adulthood in the relative influences from different levels would support the equivalent-structural-influences position.

Method

Participants

The initial cross-sectional sample for this study consisted of a total of 3,416 adults, 65% of whom were female. The sample

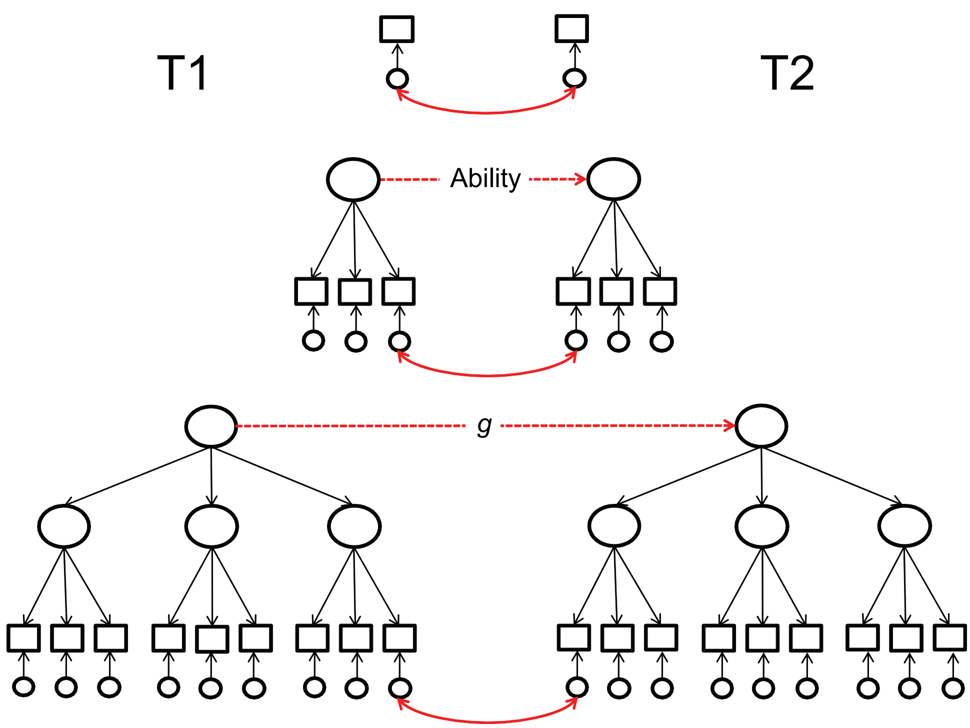

Fig. 1. Schematic illustration of the method used to infer the extent to which influences at different levels contribute to cognitive change. Boxes represent observed scores, small circles represent residual variance, and large circles represent latent constructs. The top panel portrays the covariance (double-headed arrow) between scores on a test of cognitive ability (e.g., word recall) at two measurement occasions (T1 and T2) when those scores are considered in isolation, the middle panel portrays the covariance between the same scores when a relation between the first and second measurement occasions is specified at the ability level (e.g., episodic memory), and the bottom panel portrays the covariance when a relation is specified at the *g*-factor level.

ranged from 18 to 89 years of age (*M* = 50.3, *SD* = 18.2). All participants had scores above 26 on the Mini-Mental State Exam (Folstein, Folstein, & McHugh, 1975), which is often used to screen for dementia. The average number of years of education in this sample was 15.8 (*SD* = 2.7), and the correlation between number of years of education and age was .20. The average self-rated health on a scale from 1, *excellent*, to 5, *poor*, was 2.1 (*SD* = 0.9), and the correlation between health and age was –.10.

After an average interval of 2.6 years (*SD* = 1.2), 1,490 of the participants returned for a second measurement occasion. This longitudinal subsample was very similar to the total cross-sectional sample with respect to number of years of education and self-rated health (details on comparisons of the cross-sectional and longitudinal samples are reported in Salthouse, 2010b). The number of participants in each age decade ranged from 159 to 781 in the cross-sectional sample, and from 64 to 379 in the longitudinal sample. So that all available data, including the data from participants who were tested only once, could be used in deriving the estimates, the analyses were conducted with the Full Information Maximum Likelihood algorithm in AMOS (Arbuckle, 2007).

Cognitive tests

Sixteen different cognitive tests selected to represent five cognitive abilities were administered at each occasion (see Salthouse, 2004; Salthouse & Ferrer-Caja, 2003; Salthouse, Pink, & Tucker-Drob, 2008). Vocabulary ability was assessed with Definition Vocabulary, Picture Vocabulary, Synonym Vocabulary, and Antonym Vocabulary tests; reasoning ability was assessed with a Matrix Reasoning test, a Series Completion test, and a test requiring identification of unique letter sets; spatial-visualization ability was assessed with Spatial Relations, Paper Folding, and Form Boards tests; memory ability was assessed with Word Recall, Paired Associates, and Logical Memory tests; and perceptual-speed ability was assessed with Digit Symbol, Pattern Comparison, and Letter Comparison tests. Prior research established that the tests were all reliable, and valid in the sense that they had moderate to high loadings on their respective ability factors; very similar patterns in factor loadings for adults of different ages indicated that the tests had equivalent validity across ages (e.g., Salthouse, 2004; Salthouse & Ferrer-Caja, 2003; Salthouse et al., 2008).

Results

Scores for each test were first converted to *z* scores based on the mean and standard deviation for that test at the first measurement occasion (T1). Relations between age and changes in individual test scores and between age and changes in the latent ability constructs were then examined. Longitudinal change for each test was calculated by subtracting the T1 score from the T2 score, and estimates of change in the latent constructs were derived from a latent change model (Ferrer & McArdle, 2010). The changes were positive at young ages and negative at older ages, but the age trends were primarily linear, as only a few quadratic trends were significant, and all of the quadratic trends were small relative to the linear trends. The correlations with age ranged from −.04 to −.19 for changes in individual test scores, and from −.20 to −.51 for changes in the latent constructs. Every cognitive ability exhibited a pattern of more negative longitudinal change with increased age.

A hierarchical structure was created for each measurement occasion; in these models, either three or four tests represented each of the five abilities, which were then related to the highest-order, *g*, factor (as in Salthouse, 2004). This simple model has been found to provide a good representation of the individual differences in the cognitive abilities and to be robust across independent samples (Salthouse, 2004; Salthouse & Ferrer-Caja, 2003; Salthouse et al., 2008).

The next set of analyses examined longitudinal measurement invariance of the ability structure across the T1 and T2 occasions. An initial analysis revealed that the higher-level structural relations were similar at the two occasions, as there was no significant difference in χ^2 (i.e., $\Delta\chi^2$ of 1.4 for Δdf of 4) when relations from *g* to the abilities were constrained to be equal over time, rather than allowed to vary freely.

Separate analyses for the individual abilities indicated that there were significant increases in χ^2, indicating loss of fit, when factor loadings, intercepts, or unique variances were constrained to be equal at T1 and T2. However, the absolute level of fit for all abilities was quite good even with all constraints (i.e., confirmatory fit index, or CFI > .98; root mean square error of approximation, or RMSEA < .06).[1] This good fit suggests that although the constructs at the two occasions were not identical, they were nevertheless very similar. As a check on the validity of the assumption that the measurement models were nearly equivalent across the two occasions, the analyses described next were repeated after constraining the factor loadings to be equal at T1 and T2. In all respects, the results were nearly identical to those in the models with no constraints, and therefore only the results from models without constraints are described here.

Following the logic outlined in the introduction, covariances of the residuals for each test score were examined when the test was considered in isolation (*A*) and after specifying a T1-T2 relation either at the ability level (*B*) or at the highest-order, *g*, level (*C*). For each test, two proportions were created: one representing the influence from the ability level or higher on the T1-T2 covariance in the target test score (i.e., $[A - B]/A$) and the other representing the influence from the *g* level (i.e., $[A - C]/A$). The proportional influence from the *g* level was subtracted from the proportional influence from the ability level to represent the influence unique to the ability level, and the proportional influence from the ability level was subtracted from 1.0 to represent the test-specific influence. Figure 2 presents the averages of these two estimates, along with the estimate of the proportional influence when a T1-T2 relation

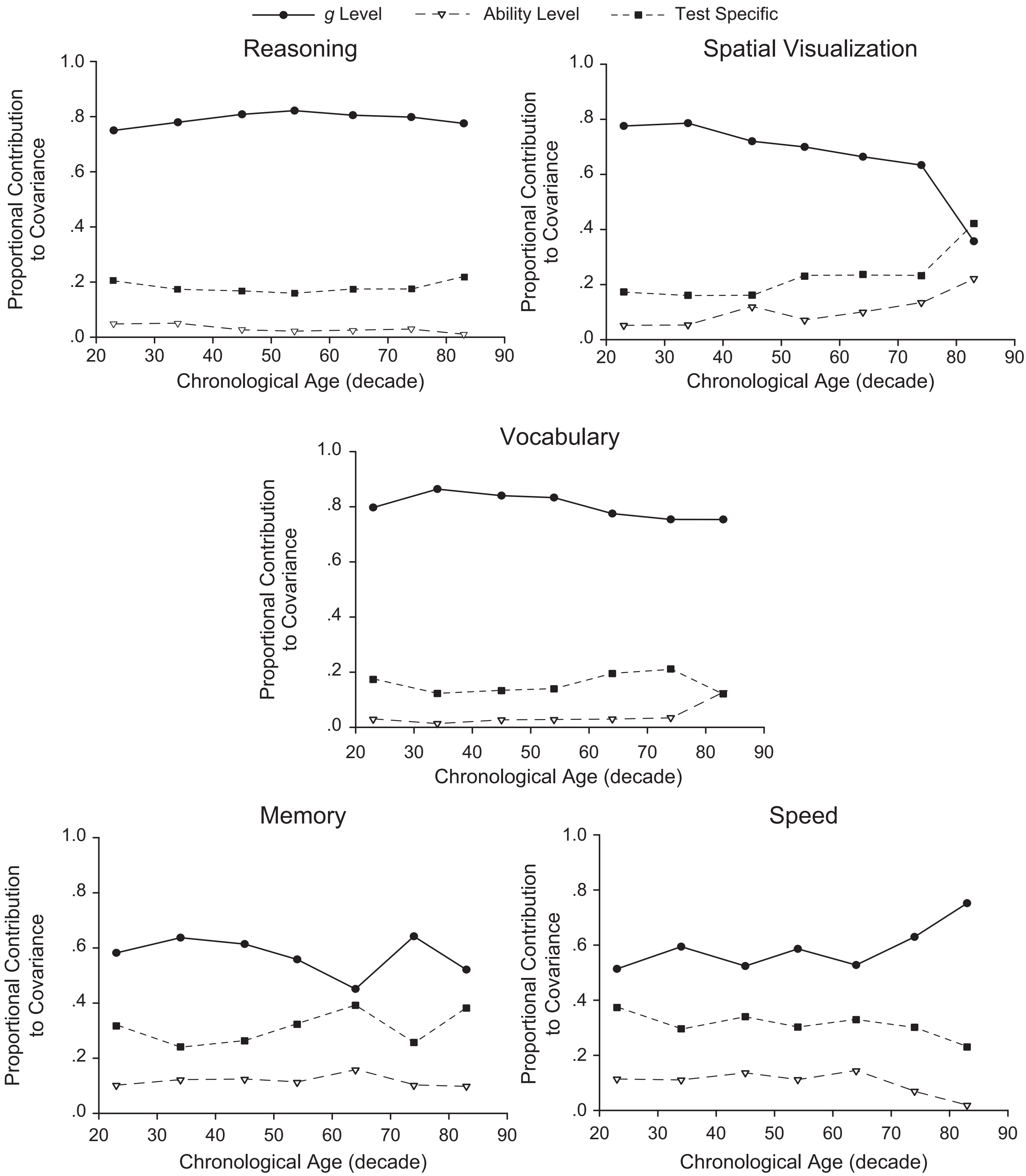

Fig. 2. Estimates of the proportional contributions of three levels of cognitive ability to the covariances for tests representing five abilities. For each ability, the contributions of influences at the *g* level, influences unique to the ability level, and test-specific influences are graphed as a function of age decade.

was specified at the *g* level, as a function of age decade, separately for each of the five abilities. It is important to note that the estimate at the ability level reflects only the unique contribution not shared with influences from the *g* level, and that the estimate of test-specific influences includes measurement error.

Several features of the data in Figure 2 are noteworthy. First, the inferred influences unique to the ability level were very small for tests reflecting reasoning and vocabulary abilities. Second, the influences from the *g* level were smaller for memory and speed tests than for reasoning, spatial visualization, and vocabulary tests. Finally, of greatest importance in the current context was the finding that nearly all of the functions in Figure 2 were nearly flat, which indicates that there was little systematic relation between age and the level of the influences on cognitive change. The only exceptions were in the decade of the 80s: The influences on change in perceptual speed and spatial visualization ability were in opposite directions during this decade, as *g* involvement in cognitive change increased for speed tests but decreased for spatial visualization tests.

Discussion

As has been reported elsewhere (i.e., Salthouse, 2010b, 2011), longitudinal change in cognitive test scores and abilities was systematically more negative as age increased. The key question in the current study was whether the more negative changes at older ages were associated with shifts in the relative influences from different levels in the hierarchical structure of cognitive ability. Relations between T1 and T2 individual test scores reflect the sum of influences originating at all levels, and the proportional reductions in the covariance of the test scores when T1-T2 relations are specified at higher levels are informative about influences operating at higher levels. That is, the proportional reduction in the covariance when a T1-T2 relation is specified at the ability level is an estimate of the contribution of change at or above the ability level to the relation between the test scores on the two occasions. In an analogous manner, the proportional reduction in the covariance when a T1-T2 relation is specified at the *g* level is an estimate of the contribution of change at the *g* level to the across-occasion relation between the test scores.

The tests representing reasoning and vocabulary abilities had large influences from the *g* level (see Fig. 2), which suggests that most of the common contribution to the covariance for the individual tests of reasoning and vocabulary was at the highest level in the hierarchy. In contrast, tests reflecting spatial visualization, memory, and speed abilities had weaker influences from the *g* level, a result implying less commonality with the highest-order factor. However, it is important to bear in mind that the results in Figure 2 show little evidence of age-related shifts in the level at which change operates.

Despite the systematically more negative cognitive change associated with increased age, the variability, reliability, stability, and correlates of change have been found to be similar across most of adulthood (Salthouse, 2010a, 2010b, 2010c). The current study has extended this list by demonstrating that there is also little relation between age and the level at which cognitive change operates. Furthermore, there is little evidence in these results for either the dedifferentiation or the disintegration interpretations because the proportional contributions to change from different levels in the hierarchy were similar at all ages. Therefore, although increased age is associated with more negative quantitative change, there is little evidence of qualitative differences in the nature of cognitive change among healthy adults across the span from about 20 to 90 years of age.

Declaration of Conflicting Interests

The author declared that he had no conflicts of interest with respect to his authorship or the publication of this article.

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Note

1. Fits to the data are better when CFI values approach 1.0 and RMSEA values approach 0.

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