Psychon Bull Rev (2016) 23:932–939
DOI 10.3758/s13423-015-0910-8

Continuity of cognitive change across adulthood

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Published online: 4 August 2015

Abstract Although cross-sectional (between-person) comparisons consistently reveal age-related cognitive declines beginning in early adulthood, significant declines in longitudinal (within-person) comparisons are often not apparent until age 60 or later. The latter results have led to inferences that cognitive change does not begin until late middle age. However, because mean change reflects a mixture of maturational and experiential influences whose contributions could vary with age, it is important to examine other properties of change before reaching conclusions about the relation of age to cognitive change. The present study was designed to examine measures of the stability, variability, and reliability of change, as well as correlations of changes in memory with changes in speed in 2,330 adults between 18 and 80 years of age. Despite substantial power to detect small effects, the absence of significant age differences in these properties suggests that cognitive change represents a qualitatively similar phenomenon across a large range of adulthood.

Keywords Aging · Cognition and aging · Cognitive aging

A considerable number of data exist relating cognitive performance to adult age in nationally representative samples assessed with commercial cognitive test batteries (see Salthouse, 2010b, for a review), in large convenience samples tested in the laboratory (e.g., Ronnlund, Nyberg, Backman, & Nilsson, 2005; Schaie, 2013), over the telephone (e.g., Lachman, Agrigoroaei, Tun, & Weaver, 2014), on the Internet (e.g., Hampshire, Highfield, Parkin, & Owen, 2012; Johnson, Logie, & Brockmole, 2010; Logie & Maylor, 2009; Murre, Janssen, Rouw, & Meeter, 2013; Sternberg et al., 2013), and with videogames and personal electronic devices (e.g., Lee et al., 2012; Thompson, Blair, & Henrey, 2014). Although there is often an increase in average performance until the age decades of the 60s or 70s for measures of general knowledge or vocabulary (Salthouse, 2014d), the dominant pattern with measures of the efficiency or effectiveness of processing at the time of assessment is negative age relations starting when people are in their 20s or 30s.

The data in Fig. 1 illustrate this phenomenon with results on a speeded substitution test from nationally representative samples used to establish the norms in different versions of the Wechsler Adult Intelligence Scale. Note that the functions relating performance (in *z*-score units) to age are nearly parallel in the three time periods, with mean performance about .5 standard deviations above the sample mean for adults in their 20s, and about 1.0 standard deviations below the sample mean for adults in their 70s.

The age–cognition relations with cross-sectional data are quite consistent, but cross-sectional comparisons are sometimes considered misleading, because assessments at different ages are based on different people who could vary in characteristics other than age that might affect their levels of cognitive functioning. Because longitudinal studies are based on comparisons of the same people tested at different ages, they are often assumed to be more informative about age-related influences than are cross-sectional studies. It is therefore noteworthy that although some reports have described significant longitudinal declines among adults in their 40s and 50s, particularly for measures of speed (e.g., Anstey, Sargent-Cox, Garde, Cherbuin, & Butterworth, 2014; Salthouse, 2011a, 2014a; Schaie, 1989; Singh-Manoux et al., 2012), significant within-person decline is typically not evident until adults are

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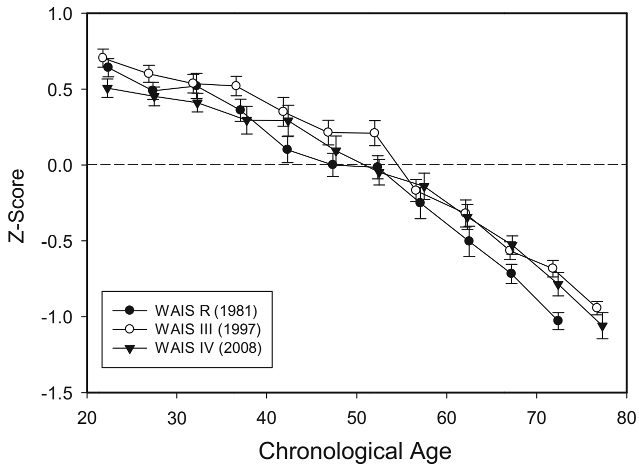

Fig. 1 Means (and standard errors) of sample-specific *z* scores as a function of age on the Digit Symbol Coding Test in nationally representative samples at three different time periods

in their 60s or later (Bielak, Anstey, Christensen, & Windsor, 2012; Giambra, Arenberg, Zonderman, Kawas, & Costa, 1995; Salthouse, 2010c; Schaie & Hertzog, 1983; Zelinski & Burnight, 1997).

Results such as these have been interpreted as indicating that little or no cognitive change occurs before about 60 years of age. However, the claim that cognitive change does not begin until the 60s or later warrants careful examination, because it has both theoretical and practical implications. For example, the search for causal factors contributing to cognitive decline could productively focus only on the period of middle or late adulthood if cognitive change does not occur until age 60 or later. Moreover, if cognitive change is exclusively a late-life phenomenon, efforts to distinguish normal and pathological trajectories, and interventions designed to minimize age-related declines, might safely ignore the periods of young and middle adulthood. However, both the search for causes and attempts to distinguish normal and pathological trajectories may be unproductive if the phenomenon of cognitive aging originates early in adulthood and adults in this age range are not included in the research.

Most of the prior research that has led to the conclusion that cognitive change begins in middle age or later has focused only on the mean value of change, and has not considered other important properties of change such as stability, variability, reliability, and correlations with changes in other cognitive abilities. This is unfortunate because, regardless of the relations of age with mean change, increased age might be associated with (a) lower stability of scores, if there is more across-occasion fluctuation in performance at older ages; (b) larger variability of change, if there is greater divergence of change trajectories at older ages; (c) higher reliability of change, if a greater proportion of the variability in change is systematic at older ages; and (d) larger correlations of changes with one another, if the influence of a general factor of change is greater at older ages.

Each of these characteristics is relevant to the issue of whether cognitive change represents the same phenomenon at different ages, but few systematic comparisons of their relations to age have been reported. To illustrate, although it is frequently assumed that individual differences in cognitive change are larger at older ages, only a limited number of comparisons of change variability at different ages have been published, and the results have been inconsistent. For example, Reynolds, Gatz, and Pedersen (2002) reported greater change variance at older ages in some, but not all, cognitive measures, and little relation of age to change variability has been found in other studies (e.g., Finkel, Pedersen, Plomin, & McClearn, 1998; Giambra et al., 1995; Huppert & Whittington, 1993; Ronnlund & Nilsson, 2006). Furthermore, the figures in Salthouse (2011a) and Salthouse (2012a) revealed nearly constant standard deviations of change at different ages in cognitive measures from different data sets. A study by de Frias, Lövdén, Lindenberger, and Nilsson (2007) is sometimes cited as having shown age-related increases in change variance, but this interpretation may be misleading, because the authors noted that "The majority of the variances were non-significant, which makes statistical comparisons across age groups redundant . . . [and] interindividual differences in change tend to increase in old age, but could not be detected for the majority of the measures and age groups" (p. 387).

Limited information is also available about age differences in the magnitude of the correlations among changes in different cognitive abilities. In analyses of a subset of the present data, Tucker-Drob (2011) found no significant differences in the relations among changes in different cognitive domains. In another data set, Tucker-Drob, Reynolds, Finkel, and Pedersen (2014) noted that correlations of changes in different cognitive variables were smaller for adults between 50 and 65 years of age than for adults between 65 and 96 years of age, but direct statistical comparisons of the age differences in the correlations were not reported.

The goal of the present study was to examine the properties of cognitive change in adults between 18 and 80 years of age who participated in the Virginia Cognitive Aging Project (VCAP) on at least two occasions. This project is ideally suited to investigate the relations between age and cognitive change, because it involves moderately large numbers of adults across a wide age range who have participated in at least two longitudinal occasions in which they performed multiple tests of several cognitive abilities. Key questions to be addressed were the relations of age with the properties of cognitive change from a first to a second measurement occasion, including not only the mean value of change, but also its stability, variability, reliability, and correlations with changes in other cognitive abilities. As was noted above, each of these properties might be expected to exhibit significant age differences if cognitive change represents qualitatively different phenomena at different periods in adulthood.

Method

Sample

The present analyses were restricted to adults under 81 years of age at the first measurement occasion, to minimize the influences of dementia and other late-life diseases that might affect cognition. Participants with Mini Mental State Exam (Folstein, Folstein, & McHugh, 1975) scores less than 24 at either the first (T1) or the second (T2) occasion were also excluded, to reduce the impact of cognitive impairment on the results. In the primary analyses, the individuals were grouped by 20-year age intervals in order to have sufficient power to detect possible age differences in relevant properties of change.

A unique feature of the VCAP study is a measurement-burst design, involving three sessions within a period of about two weeks at each occasion, during which the participants performed parallel versions of the primary tests. About half of the participants had complete scores on the second session of each occasion, which allowed correlations of the changes in the two sessions to be computed so as to estimate the reliability of change. Although the intervals between the T1 and T2 measurement occasions varied across participants (see Salthouse, 2011b, 2014c), variability across intervals was ignored in the present analyses. However, nearly identical results were obtained when the analyses were repeated on the data from participants in the middle 50 % of the distribution of T1–T2 intervals. These individuals had a mean interval across occasions of 2.52 years and a standard deviation of 0.43, as compared to the mean of 3.00 and standard deviation of 1.70 in the complete sample. Because the pattern of results among participants with a narrow range of intervals (i.e., from 2.0 to 3.2 years) was very similar to that in Table 2 in the Results, interval variability can be inferred to have had little effect on the major findings.

Characteristics of the samples in the three age groups are reported in Table 1. Note that increased age was associated with slightly poorer self-ratings of health, but also with more years of education and higher estimated IQs.

Table 1 Descriptive characteristics of the participants in three age groups

	Age Group			
	Y (18–39)	M (40–59)	O (60–80)	Age *r*
N	475	1,033	822	N/A
Age	28.1 (6.7)	50.8 (5.4)	68.3 (5.8)	N/A
Self-rated health	2.1 (0.8)	2.1 (0.9)	2.2 (0.9)	.08*
Education (years)	14.8 (2.3)	15.8 (2.6)	16.3 (2.8)	.21*
T2 MMSE	28.6 (1.6)	28.7 (1.5)	28.6 (1.5)	.00
Est. IQ	107.9 (13.7)	111.5 (14.2)	112.4 (12.8)	.09*
T1–T2 interval (years)	3.1 (2.0)	3.1 (1.7)	2.8 (1.4)	–.09*

* $p < .01$. Health is on a scale from 1 for *excellent* to 5 for *poor*. "MMSE" is the Mini-Mental State Exam (Folstein et al., 1975). "Est. IQ" was based on the scores from three tests (Series Completion, Antonym Vocabulary, and Paper Folding) previously found to have a correlation of .93 with the Wechsler IV full-scale IQ (Salthouse, 2014b). N/A indicates that the value is not applicable

Cognitive measures

Only measures of memory and speed were examined in the present analyses because these were the only two abilities with significant change variance in each age group in an earlier report (Salthouse, 2014a). The memory measures consisted of the number of words recalled across four repetitions of the same list of 12 unrelated words, the number of response terms recalled across two lists of six unrelated stimulus–response word pairs, and the number of story units recalled across two stories, with two recall attempts for the second story. The speed measures all had fixed time limits and consisted of the number of correct substitutions of a symbol for a digit according to a code table, the number of correct comparisons of line patterns, and the number of correct comparisons of sets of letters. Additional information about the measures, including their reliability and validity (in the form of loadings of the measures on relevant ability factors), is contained in other publications (e.g., Salthouse, 2009, 2014a).

Individual test scores were converted to *z*-score units based on the test score mean and standard deviation on the first occasion. For some analyses, composite scores were formed by averaging the three *z* scores for the relevant ability.

Analyses

Latent change models (McArdle & Nesselroade, 1994), with *z* scores for the relevant tests serving as indicators of the cognitive-ability constructs, were used to assess cognitive change. Details about the models used in the present study are provided in the Appendix. The advantages of these models relative to other methods of assessing change, are that they accommodate missing data with the full-information maximum likelihood algorithm, they simultaneously estimate both level and change in performance, they minimize measurement error, they allow for an evaluation of the fit of the model to the variance and covariance data, and they provide estimates of standard errors that can be used to derive effect sizes. With respect to the latter point, the standard error estimates can be converted to standard deviations by multiplying them by the square root of the sample size, and then effect size estimates (i.e., Cohen's *d*) can be computed by dividing the difference between relevant parameter values by the pooled standard deviation. All of the latent change models had good fits to the data, because the comparative fit index (CFI) values were greater than .96, and the root-mean-squared error of approximation (RMSEA) values were less than .07.

Results

Composite scores from the first session on the T1 and T2 measurement occasions are portrayed by 5-year age groups in Fig. 2 for memory, and in Fig. 3 for speed. It can be seen that the change from the first to the second occasion was positive for participants younger than about 35 years of age, but that the changes in both cognitive domains were negative at the oldest ages. Linear and quadratic relations of age were examined on the latent change estimates, and only the linear age trends were significant ($p < .01$).

Because some of the relevant measures are group-based statistics (e.g., stability, reliability, and variance), the sample was divided into three age groups for all of the remaining analyses. The results of analyses comparing the properties of change obtained from the latent change analyses in the three age groups are presented in Table 2. In addition to the means and standard errors, the entries in the three columns on the right of the table contain estimates of the effect sizes for the differences between pairs of age groups.

The mean change corresponds to the latent change estimate across the T1 and T2 measurement occasions. Consistent with the patterns in Figs. 2 and 3, the changes were positive at young ages but were progressively more negative with increased age. With both the memory and speed measures, the changes were significantly more negative at older ages in contrasts of the young and middle groups, and of the middle and old groups.

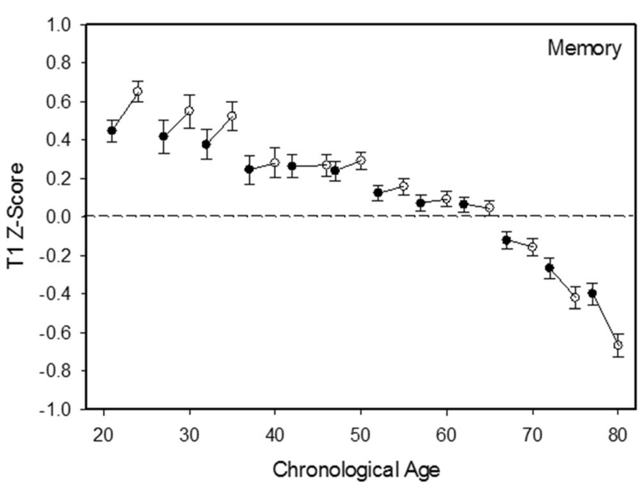

Fig. 2 Means (and standard errors) of composite memory scores on the first sessions of the first occasion (filled circles) and the second occasion (open circles)

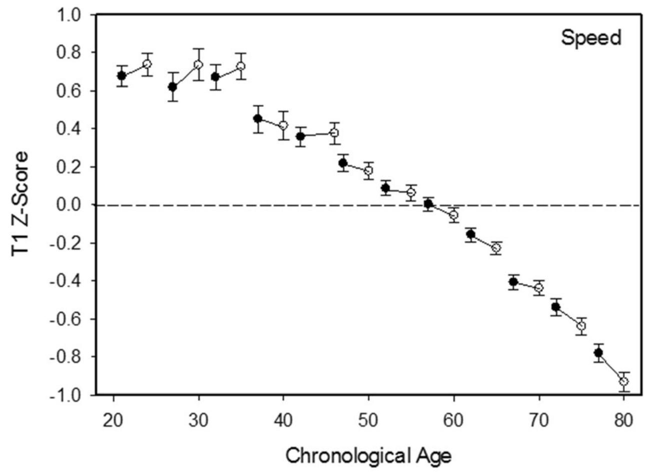

Fig. 3 Means (and standard errors) of composite speed scores on the first sessions of the first occasion (filled circles) and the second occasion (open circles)

The stability of change was assessed through the correlation between the scores of the latent ability variables at T1 and T2. All of the stability coefficients were high, and no significant age differences were apparent in the sizes of the coefficients.

Individual differences in the magnitude (and direction) of change were represented by the estimated variance in change. The change variance estimates were all significantly greater than zero, indicating significant individual differences in the amounts of change in each age group. However, comparisons across age groups revealed similar change variance in the three age groups for memory, and a nonmonotonic pattern for speed in which the middle group had significantly greater change variance than both the young and old groups.

As was noted earlier, many of the participants performed alternative versions of the tests on a second session at each occasion. The reliability of change was therefore estimated from the correlation of change from the first session of T1 to the first session of T2 with the change from the second session of T1 to the second session of T2. Because only reliable variance among the indicators can be shared, the latent-change estimates for a given set of data are not affected by measurement error. However, the reliability of the estimates within a single data set does not necessarily imply high generalizability of the change estimates from that data set to another. In fact, examination of the entries in Table 2 reveals that the correlations of the latent changes across the two sessions ranged from .50 to .82. There were no significant age differences in the reliability of memory change, but the reliability of speed change was significantly higher in the young group than in than the middle and older groups.

Finally, the correlations between change in memory and change in speed ranged from .35 to .52. No significant

Table 2 Estimates of properties of latent change (with standard errors) and estimates of effect sizes

	Age Group			Effect Size		
	Y (18–39)	M (40–59)	O (60–80)	*d*(Y-O)	*d*(Y-M)	*d*(M-O)
Mean Change						
Memory	.13 (.02)*	.03 (.02)	–.09 (.02)*	–.45*	–.20*	–.26*
Speed	.06 (.02)*	–.02 (.01)	–.08 (.01)*	–.34*	–.19*	–.13*
Stability from T1 to T2						
Memory	.91*	.91*	.89*	.07	–.02	.09
Speed	.94*	.89*	.91*	.02	.05	–.04
Variance in Change						
Memory	.09 (.02)*	.08 (.01)*	.09 (.01)*	.00	–.03	.03
Speed	.04 (.02)*	.09 (.01)*	.06 (.01)*	.05	.13*	–.11*
Reliability of Change (Correlation of Change in Session 1 with Change in Session 2)						
Memory	.52*	.50*	.76*	.01	–.06	.07
Speed	.82*	.60*	.68*	–.18*	–.04	–.13*
Correlation: Memory Change–Speed Change						
	.52*	.42*	.35*	–.04	.01	–.05

An asterisk in the Age Group columns indicates that the value is significantly ($p < .01$) different from zero, and an asterisk in the Effect Size columns indicates that the specified contrast was significantly ($p < .01$) different from zero in an independent-groups *t* test

differences were observed among the correlations, and the effect sizes for the differences between correlations were small across the three age groups.

Discussion

The results in Figs. 2 and 3 and in the first rows of Table 2 confirm prior reports of significant within-person decline in cognitive functioning only in adults 60 years of age and older. However, rather than abruptly declining at a particular age, the age–change relations were continuous throughout adulthood, with positive change at young ages, and gradually more negative change with increased age. The results from studies comparing the performance of individuals of the same age who are tested for the first time when longitudinal participants are tested for the second time suggest that much of the positive cognitive change is likely attributable to the effects of prior test experience in the longitudinal participants (e.g., Salthouse, 2009, 2014e, 2015).

Despite significant declines in mean change only at older ages, the results from other properties of change suggest that the phenomenon of cognitive change in healthy adults is qualitatively similar between about 18 and 80 years of age. Lower stability across occasions and greater variance in change might have been expected at older ages if individual differences in rates of change were larger with increased age. A higher proportion of the change might have been expected to be reliable at older ages if the change was more systematic with increased age. And finally, stronger correlations of the changes in different abilities at older ages might have been expected if influences on change were more general, and less domain-specific, with increased age. Even though the samples in the present study were moderately large, which was associated with high power to detect small effect sizes (i.e., power of at least .8 to detect an effect size of .2 in a two-tailed test with an alpha of .01), none of these expectations was supported.

The variance in change was significantly greater than zero in both the memory and speed measures in each age group, indicating that people differ in their amounts (or directions) of cognitive change. These results are consistent with the widely held assumption that some people age more gradually than others in terms of cognitive functioning. However, the most relevant information from the present perspective is not the magnitude of change variability at any given age, but instead the relation between age and variability in change. In other words, the issue is not whether there is *heterogeneity* at any given age, but whether there is *heteroscedasticity*, with greater variance at some ages than others. The results in Table 2 indicate that the differences among people in the estimates of change were not significantly larger among people in their 60s and 70s than among people in their 20s and 30s or in their 40s and 50s. A nonmonotonic relation of change variance to age was apparent with the speed measures, but age differences in speed change variance were not significant in the analysis of data from participants in the middle 50 % of the distribution of T1–T2 intervals, and thus this particular result may not be robust. Therefore, these data provide little evidence that individual differences in cognitive change are greater at older ages, when the mean change is most negative. As was noted in the introduction, little or no relation of age to variability in cognitive change has also been reported in other studies (e.g., Finkel et al., 1998; Giambra et al., 1995; Huppert & Whittington, 1993; Ronnlund & Nilsson, 2006).

The availability of measures from different versions of the same tests on the second session allowed for the reliability of change to be estimated from the correlations of the estimated changes in the two sessions. Reliability information is relevant to the qualitative nature of change at different ages because even if the total variance remained constant, increased age might be associated with a higher proportion of systematic (i.e., reliable) variance in change. However, this was not the case, since the reliability estimates were largest in the young group for the measures of speed, and no significant differences were evident for memory.

Another similar property across age groups was the magnitude of the correlations of memory change with speed change. As is evident in Table 2, there were no significant differences among the correlations, and thus no indication of an increase with age, as one might expect if a general influence on change was becoming more powerful at older ages.

The findings reported here are consistent with those from earlier reports in which different, and in many cases less powerful, analytical procedures were used with subsets of the participants from the present data set. That is, few or no age differences have been reported in measures of across-occasion stability (i.e., Salthouse, 2010c, 2012a, 2014a), variance of change (i.e., Salthouse, 2010c, 2012a, 2014a), or reliability of change (i.e., Salthouse, 2010c, 2012c), nor in the correlations between changes in different cognitive measures (Salthouse, 2010a, 2010c, 2012c; Soubelet & Salthouse, 2011). Furthermore, few or no age differences have been found in other properties of change, including effects of the length of the interval between measurement occasions on the magnitude of change (Salthouse, 2011c), effects of an intervening assessment on change (Salthouse, 2014c), the level at which change occurs in a hierarchical structure (Salthouse, 2012b), and the magnitude of the relations of change with other variables (i.e., Salthouse, 2010c, 2011a, 2012c, 2014a; Soubelet & Salthouse, 2011). When considered in combination, the results reported here and in a number of earlier studies strongly suggest that cognitive change has similar properties at different ages in adulthood.

At least two potential limitations of the study should be noted. First, it is possible that the lack of age differences in properties of change was attributable to the older adults in the present sample having more years of education, higher estimated IQs, or a shorter average longitudinal interval than the participants in the other age groups. Although factors such as these could be operating, their effects would be expected to be greatest on mean change, and the significant age differences in mean change suggest that their influences were likely small in this study. A second possible concern is that experiential effects on change could have been greater at younger ages, which may have contributed to the positive change at young ages, and possibly inflated the change variance relative to older ages, when experiential influences on change might have been smaller. Unfortunately, rigorous evaluation of this interpretation would require separate estimates of the experiential and maturational components of change in adults of different ages that are not yet available.

To summarize, even though significant negative change may not be detected until late middle age, the relations of cognitive change to age appear to be primarily linear, with no discrete shift when the decline is first significantly less than zero. Furthermore, the lack of age differences in other properties of change suggests that the processes operating in one's 60s and 70s are qualitatively similar to those operating in one's 20s and 30s. Taken together, these results are consistent with the idea that cognitive change represents the same phenomenon at different ages, and hence may involve similar mechanisms, and causes, throughout adulthood. Efforts to understand, and ultimately to modify, both pathological and normal cognitive aging should therefore consider the entire range of adulthood, and not merely a segment in late life in which the mean declines are most pronounced.

Author note This research was supported by National Institute on Aging Grant Number R37AG024270. The content is solely the responsibility of the author and does not necessarily represent the official views of the National Institute on Aging or the National Institutes of Health. There are no conflicts of interest.

Appendix

The latent-change models were analyzed with the Amos (Arbuckle, 2013) structural equation modeling program. Scores on the three tests representing the relevant ability (i.e., memory or speed), administered on each occasion were converted to *z*-score units based on the T1 means and standard deviations. These scores were then used to define occasion-specific latent-ability variables with equal factor loadings, intercepts, and residual variances of the indicator variables on each occasion. The second-occasion latent variable (LV2) was regressed, with a fixed regression weight of one, on the first-occasion latent variable (LV1) to create a residual latent variable representing across-occasion change (LVChange). Because the LV2 factor is defined as LV1 plus LVChange, rearrangement of the terms indicated that LVChange = LV2 – LV1. This formulation of longitudinal change not only yielded an estimate of change without measurement error, but also provided estimates of the mean and variance of change and the standard error of each parameter.

Interpretation of the results of the latent-change models was based on the assumption that the latent variables had the same meaning at each occasion. This assumption was investigated with the four-step procedure described in Widaman, Ferrer, and Conger (2010). Model 1 was a configural invariance model that included the across-time correlations of the factors and of the residuals for each variable, but no constraints on the parameter estimates at each occasion. Model 2 was a weak-factor-invariance model that differed from Model 1 in that the factor loadings were constrained to be equal at each occasion. Model 3 was a strong-factor-invariance model that differed from Model 2 in that the intercepts (the means of the manifest variables) were also constrained to be equal across occasions. The final model, Model 4, was a strict-factor-invariance model that differed from Model 3 in that the unique variances for the variables were also constrained to be equal at each occasion.

The difference in the chi-square test indicated significant loss of fit when progressively more constraints were imposed across successive models. However, the absolute fit was very good (i.e., CFI > .985, and RMSEA < .064) for all models, including the strict-factor-invariance model incorporating all constraints. It was therefore concluded that the latent variables had very similar meanings on both measurement occasions.

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