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Contributions of the Individual Differences Approach to Cognitive Aging

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Abstract

Objective: To review selected research in cognitive aging incorporating an individual differences approach.
Method: Three contributions of the individual differences perspective in cognitive aging are illustrated with data from the Virginia Cognitive Aging Project.
Results: Research capitalizing on the variability among individuals has been used to: (a) improve sensitivity and validity of measurement of cognitive functioning, and evaluate possible age differences in the meaning of the measures; (b) investigate relations between age and individual cognitive measures in the context of other types of cognitive measures; and (c) examine the degree to which age-related influences on target measures are statistically independent of age-related influences on other cognitive measures.
Discussion: Although the primary focus of much of the research in cognitive aging has been on mean differences between people of different ages, people differ in many respects besides age. A fundamental assumption of the individual differences perspective is that at least some of those differences may be informative about the nature, and causes, of the relations between age and cognitive functioning.

Keywords: Research methods and issues—Measurement—Intellectual functioning—Cognition

In a classic article, Cronbach (1957) pointed out that two approaches to research in psychology could be identified. One was the experimental approach in which the primary focus was on group means, with individual variation around the means often considered random error. The second was the correlational approach, which instead of viewing individual differences as error, treated them as meaningful variations in the degree to which the relevant characteristic was manifested. In addition to the difference in emphasis on group means versus individual variability, the approaches also tend to differ in whether the analyses are primarily univariate (single variable) as in experimental research or multivariate (multiple variables) as in correlational research.

Although the existence of two broad approaches to psychological research is well accepted, no consensus exists on exactly what constitutes the individual differences approach in cognitive aging. In order to provide a framework for the subsequent discussion, it is proposed that the defining property of the individual differences approach in cognitive aging is that nontarget measures assessed in the same individuals are used to assist in the interpretation of age relations on target measures. This definition is not ideal because the distinction between target and nontarget measures can be ambiguous, and the emphasis on assisting the interpretation of age relations on target measures could lead to the omission of important studies capitalizing on individual differences. Nevertheless, this working definition captures the fundamental idea that differences among individuals have the potential to provide valuable information about the nature of cognitive aging.

Conceptualizing the individual differences perspective on cognitive aging in this manner allows its history to be traced to some of the first studies in the field. For example, several early researchers equated participants on measures of general cognition or intelligence before examining age differences in the measures of primary interest (e.g., Bromley, 1956, 1958, 1967; Foster & Taylor, 1920; Ruch, 1934; Thorndike et al., 1928). Other early studies included multiple cognitive measures to compare the relative magnitude of age differences across measures (e.g., Bilash & Zubeck, 1960; Birren & Morrison, 1961; Foster & Taylor, 1920; Gilbert & Levee, 1971; Horn, 1967; Jones & Conrad, 1933; Schaie, 1958; Sward, 1945). Beginning in the 1960s and 1970s, increasing numbers of studies reported correlation-based analyses in which individual differences in some cognitive measures were statistically controlled when examining age differences in other cognitive measures (e.g., Farrimond, 1967; Hultsch, 1969; Hultsch, Nesselroade, & Plemons, 1976). In recent years, two of the leading researchers incorporating an individual differences perspective in cognitive aging were John Horn and Warner Schaie who together with their colleagues published important studies and introduced major methodological innovations, some of which are discussed later.

The remainder of this article discusses three contemporary applications, or contributions, of the multivariate, individual differences approach to cognitive aging that have emerged over the past 50 years. Although the applications are relevant with both cross-sectional and longitudinal data, the discussion will focus on cross-sectional comparisons because they are the most common type of data in cognitive aging.

In order to provide concrete examples, the applications will be illustrated with data from the Virginia Cognitive Aging Project (VCAP). All of the methods have been used with other data sets, but VCAP has the advantages of including a large sample of adults across a wide and continuous age range who have each performed a total of 16 cognitive tests representing 4 primary cognitive abilities (i.e., memory, speed, reasoning, and space) and an achievement (vocabulary). Details about the cognitive measures, and information about the project participants, are available in prior publications (e.g., Salthouse, 2014; Salthouse, Pink, & Tucker-Drob, 2008).

Improving Measurement

When a researcher relies on a single measure he or she can be considered to be implicitly assuming a one-to-one correspondence between measure and theoretical construct. However, the validity of this assumption can be questioned because all psychological measures can be postulated to have multiple influences, including not only those attributable to the relevant construct but also higher order influences associated with what is common to other constructs, lower order influences associated with the particular methods and materials used in the assessment of the measure, and random fluctuation or measurement error.

An important advantage of the individual differences approach is that it provides a means of disentangling these different influences. That is, task-specific aspects can be minimized and construct-relevant aspects maximized by aggregation of different measures of the construct obtained from the same individuals, and measurement error can be minimized with the use of latent variables defined by the reliable variance shared across multiple measures. Some of these effects can be illustrated with a comparison of reliabilities of measures across different types of aggregation. Because participants in VCAP performed different versions of the same tests on three sessions each separated by approximately 1 week (e.g., Salthouse, 2007), reliability can be assessed with the correlation of relevant scores across the first and second sessions. The across-session correlations were .75 for a measure of word recall based on the sum of items recalled across 4 repetitions of the same 12-word list; .85 for a composite memory measure based on the average *z*-score for word recall, paired associates, and logical memory measures; and .96 for a latent variable based on the same 3 memory measures. These values indicate that the proportion of systematic variance in the assessments, which is potentially available to be associated with other variables such as age, varies according to the number of measures used in the assessments and the manner in which the measures are aggregated.

In addition to improving reliability, and indirectly sensitivity, the availability of multiple measures also allows validity to be investigated by examining the patterns of relations of the target measure with other measures assumed to represent the same, and different, constructs. This form of validity, known as construct validity, is based on the assumption that measures reflecting the same theoretical construct would be expected to have moderate correlations with one another (i.e., exhibit convergent validity) and weak correlations with measures of different constructs (i.e., exhibit discriminant validity).

One noteworthy example of a cognitive aging study in which construct validity was examined was a report by Schaie, Willis, Jay, & Chipuer (1989). These researchers found that a multiple-choice vocabulary measure from a test battery originally designed for children between 11 and 14 years of age had stronger relations with perceptual speed measures than with other vocabulary measures (i.e., standardized factor loadings of .66 on a perceptual speed factor and .39 on a vocabulary factor). Although the test was intended to assess vocabulary knowledge, the results suggest that, probably because of the low difficulty level of the items in their sample of adults, the test reflected how quickly individuals could respond more than how much word knowledge they possessed.

Similar types of correlation-based procedures have been used to investigate the meaning of different cognitive measures by examining their associations with established dimensions of cognitive functioning. For example, Salthouse and colleagues have used an analytical procedure they termed contextual analysis in which the target measures, and their relations with age, are analyzed in the context of reference cognitive abilities and achievements. Many researchers have relied on subjective task analyses to infer the meaning of measures, but an advantage of contextual analyses is that they provide an objective method of determining the contributions of different abilities to the target measure. The rationale for the method was described by Salthouse and Davis (2006, p. 52) as follows:

> … one way to investigate the meaning of a variable is to determine the cognitive abilities to which it is and is not related. If people who are high in ability X perform better on variable A than people who are low in ability X, then it can be inferred that variable A likely involves some of the same processes that contribute to ability X. In contrast, if people who are high in ability Y do not differ from people who are low in that ability in their performance on variable A, then it can be inferred that the processes involved in ability Y probably do not contribute to variable A.

Results from contextual analyses with memory measures as the target variables will be used to illustrate how the method can be relevant to theoretical speculations regarding the meaning of measures. In each case, the participants performed tests of fluid intelligence (i.e., a combination of inductive reasoning and spatial visualization), verbal episodic memory, perceptual speed, and vocabulary knowledge, in addition to tests assessing the target measures. The entries in Table 1 are standardized relations of the target measure with each of these established cognitive domains.

Target measures in the first study were measures of performance in different serial positions in a free recall task. Because the strongest relations with memory ability were with to-be-remembered items in the middle positions, which are often assumed to reflect long-term memory, and the weakest relations were with items in the recency segment, which is often interpreted as a reflection of a separate short-term memory (e.g., Craik, 1968), the results support a distinction between two types of memory. The second study summarized in Table 1 found that there was a moderate relation of memory ability with the number of recognized words classified as “remembered,” but no relation with memory ability was apparent for the number of recognized words classified as “known.” This pattern is consistent with the theoretical distinction between processes of deliberate recollection (presumed to contribute to “remembered” responses) and of familiarity (presumed to contribute to “known” responses) in recognition memory (e.g., Jacoby, 1991). Another comparison in Table 1 was based on the Deese Roediger McDermott paradigm (e.g., Roediger & McDermott, 1995) and revealed that true recognition, assessed by subtracting false alarm rate to new items from hit rate, was moderately related to memory ability but that false alarms to critical lures was not. These results are consistent with an interpretation that true memory for previously presented items involves somewhat different processes than false memory. Results from the final study in Table 1 indicate that performance in memory tasks with figural and location stimuli had weaker relations with

Table 1. Standardized Coefficients Relating Reference Cognitive Domains to Target Cognitive Measures

	Cognitive domain			
Target measure	Memory	Fluid	Speed	Vocabulary
Krueger and Salthouse (2011)—different serial positions in free recall				
Primacy positions (1–3)	.46*	−.08	.13*	−.12*
Middle positions (4–9)	.75*	−.17*	.13*	−.23*
Recency positions (10–12)	.22*	−.06	.10	−.04
Salthouse and Siedlecki (2007)—different response classifications in recognition				
“Remember”	.40*	−.23	−.03	.15
“Know”	−.05	.16	.07	.10
Salthouse and Siedlecki (2007)—true (HR-FAN) and false (FACL) memory				
HR-FAN, Experiment 1	.43*	−.10	.01	.21*
HR-FAN, Experiment 2	.34*	−.11	.22	.18
FACL, Experiment 1	.10	−.19	−.03	.18
FACL, Experiment 2	.03	−.07	.15	.22*
Siedlecki and Salthouse (2014)—different types of stimulus material				
Words	.85*	−.08	.35*	−.19
Figures	.35*	.68*	.14	−.26*
Locations	.03	.80*	.21*	−.17

Note: HR-FAN, Hit Rate–False Alarm to New Items; FACL, False Alarm to Critical Lures.
*$p < .01$.

(verbal) memory ability, but stronger relations with fluid ability, than performance in tasks with word stimuli. These findings are noteworthy because the same procedures were used with each type of material, but the differential relations suggest that different abilities are involved in memory for figural, location, and verbal stimuli.

Many other target measures, and reference cognitive abilities, could be used with analyses such as those reported in Table 1. Regardless of the combination of target measures and reference abilities, however, capitalizing on individual differences in this manner has the potential to provide useful information about the meaning of cognitive measures, regardless whether the target measures are derived from psychometric tests or from experimental paradigms.

A particularly valuable application of the multivariate individual differences approach in cognitive aging research involves determining whether measures have the same meaning, and exhibit measurement equivalence, at different ages. As noted by Schaie et al. (1989, p. 652):

> A critical assumption that underlies evaluation of quantitative change across age or differences between different age groups is that the relationship between the ability constructs and measures of these constructs … remains invariant across comparisons. That is, quantitative comparisons are meaningful *only* if there is qualitative invariance …

Formal statistical procedures have been developed to investigate measurement equivalence by examining properties, such as factor loadings, means, and variances, in different age groups or at different measurement occasions in longitudinal comparisons (e.g., Widaman, Ferrer, & Conger, 2010). However, the basic principle can be illustrated with correlations of the word recall measure with other memory measures and with speed measures. That is, if the word recall measure primarily represents memory ability, its correlations with other memory measures would be expected to be moderately high and exhibit convergent validity, whereas its correlations with speed measures would be expected to be lower and exhibit discriminant validity. Moreover, if construct validity is comparable across adulthood, the two sets of correlations should be nearly the same magnitude at different ages.

The relevant correlations from VCAP data are portrayed as a function of age decade in Figure 1. It can be seen that the correlations of the recall measure were higher with the paired associates and logical memory measures assumed to represent the same construct (i.e., memory) than with the digit symbol, letter comparison, and pattern comparison measures postulated to represent a different construct (i.e., speed). Of particular importance in the current context is that the same pattern of convergent and discriminant validity was evident in different age decades. With these measures and participants, therefore, the recall measure can be inferred to have similar meaning at different ages.

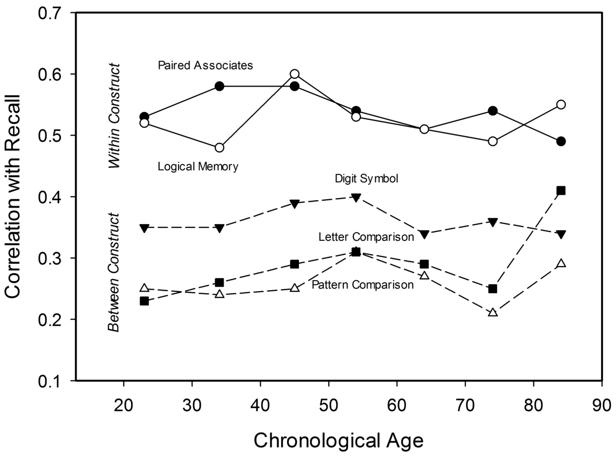

Figure 1. Correlations of a word recall measure with measures of memory and speed in different age groups.

Interim summary

An important contribution of the multivariate individual differences approach is that it can be used to improve measurement quality by enhancing reliability through aggregation and allowing validity to be evaluated based on patterns of relations with other measures of the same and different constructs. Furthermore, these procedures can be used to investigate whether differences across age groups, or across longitudinal occasions, are more consistent with a quantitative shift in the same constructs or a qualitative shift in the nature of the constructs being evaluated.

Investigating Interrelations Among Measures

A popular analytical procedure based on multivariate individual differences data involves determining whether the pattern of relations among the measures is consistent with age differences in nontarget measures contributing to, or mediating, age differences in a target measure. That is, results from meditational analyses, in which statistical procedures are used to control the variability in selected nontarget measures, are considered informative about what might be expected on the target measure if there had been no variation among participants in the nontarget measures.

A study by Horn, Donaldson, & Engstrom (1981) may have been one of the first to use a mediational approach in cognitive aging. These researchers investigated relations between age and a composite measure of fluid intelligence after statistically controlling measures hypothesized to reflect potentially critical processes such as working memory, associative memory, and sensory detection. The rationale was that the contribution of another variable to the age-fluid intelligence relation could be inferred from the magnitude of reduction in the relation after partialing the variance in the other variable. Based on their results, Horn and colleagues concluded that age-related decline in fluid intelligence "… is associated mainly with defects in processes of organizing information; becoming alert to new information; ignoring irrelevancies; concentrating, maintaining, and dividing attention; and holding information in working memory" (p. 33).

A large number of studies over the past 35 years have reported mediational analyses with a variety of different target and nontarget measures and with analytical procedures ranging from partial correlation and regression analysis to path analysis and structural equation modeling (e.g., Anstey, Luszcz, & Sanchez, 2001; Park et al., 2002; Salthouse, 1991; Schretlen et al., 2000; Verhaeghen & Salthouse, 1997). Mediation results can be valuable in indicating whether the observed pattern of relations is consistent with a postulated causal sequence. However, it is important to recognize that results of mediational analysis should not be considered definitive because alternative models, possibly involving different directions of the critical relations, might fit the data equally well. Mediational analyses should therefore be viewed as an opportunity for the hypothesis to survive possible disconfirmation and not as a means of confirming the hypothesis.

Another weakness of mediation models is that they focus on the relations among a limited set of measures, but because the number of possible cognitive measures is extremely large, the measures included in any given analysis necessarily represent only a subset of possible cognitive measures. This situation is portrayed in the top panel of Figure 2 in which relations are examined only among a subset of the possible measures, while other potentially informative measures are ignored.

An alternative to the mediation approach, and its focus on a restricted set of measures, involves postulating a structure that specifies how different cognitive measures are related to one another. One of the most popular organizational structures for measures of cognitive functioning is a hierarchical structure such as that portrayed in the bottom panel of Figure 2 (e.g., Carroll, 1993; Gustafsson, 1988; Jensen, 1998). Notice that within this simple structure, the observed measures are at the lowest level, first-order ability factors are at the next level, and

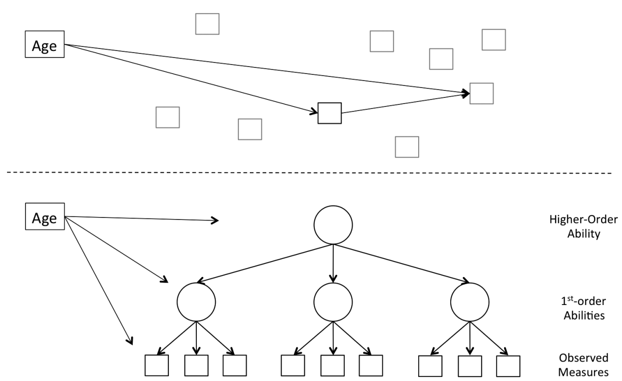

Figure 2. Schematic illustration of mediation analyses in which age relations are examined among a limited set of cognitive measures (top) and of structural analyses in which age relations are examined at different levels in a hierarchical structure of cognitive abilities (bottom).

general factors are at the highest level. The structure can be made more concrete by assuming that the box in the lower left corresponds to performance in a word recall task, with the circle above it representing memory ability and the circle at the top of the structure representing general cognitive ability (*g*).

Two advantages of organizing cognitive measures into a structure such as that in the bottom of Figure 2 are that the structure offers a framework for interpreting how different cognitive measures are related to one another, and measurement equivalence can be examined by comparison of the structures in people of different ages. Different types of organizational structures can be postulated, but the finding of roughly comparable correlations among measures at different ages suggests that the structures are similar across adulthood (e.g., Brickley, Keith, & Wolfle, 1995; Cunningham, 1980; Parker, 1983; Salthouse, 1998; Salthouse & Ferrer-Caja, 2003; Schaie et al., 1989; Sudarshan, Bowden, Saklofske, & Weiss, in press).

Interim summary. Contrary to some interpretations, neither mediation nor structural analyses are directly informative about the causes of age relations on target cognitive measures. Nevertheless, these individual difference-based methods are valuable in indicating the broader context in which cognitive measures, and the relations of age on those measures, are embedded.

Investigating Unique Age Differences

Because over a century of research has established that most cognitive measures are moderately correlated with one another, an important theoretical issue in cognitive aging is the extent to which the age-related influences on the target measure are unique and independent of age-related influences on other cognitive measures. This is a critical question because unless general influences are controlled, many of the relations of age on the measures of primary interest may not be specific to those measures and instead may be shared with other measures. To the extent that this is the case, much of the research in cognitive aging may have been inadvertently investigating relations of age on general influences on cognition, rather than the intended specific age-related influences.

One analytical procedure used to investigate unique age relations, defined as effects that are independent of age-related influences on established dimensions of cognitive functioning, involves the contextual analysis method discussed earlier. The rationale is that:

> … age relations on the reference cognitive abilities are already well established, and therefore the primary interest is in the magnitude of the relation of age on the target variable after these influences have been taken into consideration. If there is little or no direct relation (i.e., independent of indirect relations through the cognitive abilities), then the results would be consistent with an

> interpretation that most of the age-related influences on the target variable are shared with influences on the predictor variables. (Salthouse, 2011, p. 223)

There are now a large number of studies in which contextual analysis procedures have been used to investigate unique age-related influences on a variety of target measures. Although there are some exceptions, the dominant finding in these studies has been that unique age relations were typically small and seldom significantly different from zero (e.g., Kreuger & Salthouse, 2011; Salthouse, 2011; Salthouse & Siedlecki, 2007; Salthouse, Siedlecki, & Krueger, 2006; Siedlecki & Salthouse, 2014).

Another method of investigating shared age-related influences involves controlling the variability in a measure of general cognitive functioning instead of the variability in several distinct cognitive abilities. As noted earlier, some of the first studies in cognitive aging controlled general cognitive influences when examining age effects on target measures by equating their participants on a measure of general cognitive ability (e.g., Foster & Taylor, 1920; Ruch, 1934; Thorndike, et al., 1928). More recently, Mittenberg, Seidenberg, O'Leary, & DiGiulio (1989) were explicit in articulating this issue, and describing a possible method of dealing with it, as they stated that:

> … neuropsychological test performance decline might be parsimoniously attributed to changes in generalized ability (Spearman's "*g*"*)*. Simultaneous multiple regression of all tests on age was performed to evaluate this possibility. After the common variance among measures was removed, … [only two measures] … shared significant unique variance with age. (Mittenberg et al., 1989; p. 925)

Statistical control procedures resemble matching procedures in that participants are effectively equated on the level of one or more control measures prior to examining differences in the target measure. The rationale is that any differences apparent in the target measure after variability in the other measures is eliminated can be inferred to be independent of differences that might exist in those other measures. Statistical control methods have been implemented with a variety of procedures used to estimate general influences in cognition. For example, one estimate has been based on the first unrotated principal factor (PF1), which is similar to the first principal component but is based only on variance shared with other measures instead of all of the variance as in principal components analysis. Another type of general estimate is based on a latent variable corresponding to a single common factor related to all measures, and a third is based on the highest level in a hierarchical structure such as that in the bottom of Figure 2.

Typical results of statistical control procedures can be illustrated with these three estimates of general influences (i.e., PF1, latent variable, and hierarchical *g*) based on 12 VCAP measures representing reasoning, space, memory, and speed abilities. Vocabulary measures were excluded from these analyses because they have different age trends and can be considered to represent an achievement rather than an ability. Each estimate of the general factor was significantly related to age, with coefficients in standard deviation units per year of age of −.030 for PF1, −.023 for a latent common variable, and −.027 for the highest level in the hierarchical structure.

The most interesting results from statistical control analyses are the estimates of unique age-related influences, obtained after statistical control of general influences, because they represent age differences in the target measure that remain after the individuals have been equated with respect to influences shared with other cognitive measures. Estimates of total and unique age-related effects for six different target measures are presented in Table 2. One target measure is the total number of words recalled across 4 repetitions of the same list, which is one of the 12 measures used in deriving estimates of the general factor. The other measures in Table 2 were not used in estimating the general factor and consisted of recall of a new list (B) of words, the time to complete single (e.g., numeric) and alternating (e.g., numeric and alphabetic) sequences in the connections version of the trail making test, and performance in running memory tasks with letter and position stimuli.

Inspection of the entries in Table 2 reveals that all measures had large negative age relations when they were considered alone, with unstandardized regression coefficients ranging between −.018 and −.033 *SD*s per year. However, the age relations after statistical control of the general influences were much smaller, with a range between .003 and −.013 *SD*s per year. Furthermore, the patterns of attenuated age relations were very similar with the three different estimates of the general influence, and thus the results are not dependent on a particular method of estimating general or shared variance.

In order to make the results in Table 2 more concrete, consider the running memory letters task, in which participants are asked to recall the last 4 letters in an unpredictable list of 4 to 12 letters. This task is often assumed to be a test of working memory because it requires updating of continuously changing information. When considered alone, the age relations on the running memory measure were relatively large, with a difference between 25 and 75 years of age corresponding to about .90 *SD*s (i.e., 50 years at .018 *SD*s per year). However, the age relations were much smaller, and not significantly different from zero, after control of the variance common to other cognitive measures. These results imply that all of the age-related differences in this working memory measure were shared with age-related differences in other cognitive measures and that no specific explanation would be needed to account for adult age differences in the measure after age differences in other cognitive measures are taken into consideration.

Results very similar to those in Table 2 were reported by Salthouse (2009) with measures from the WAIS IV and

Table 2. Relations of Age, in Standard Deviations per Year, on Target Measures Considered Alone and After Control of Different Estimates of the General Factor in Cognition

	After control of:			
Target measure	Alone	PF1	Common	Hierarchical
Word recall	−.023*	−.003*	−.004*	−.006*
List B recall	−.018*	−.001	.001	.002
Connect—Same sequence	−.033*	−.013*	−.010*	−.008*
Connect—Alternating sequence	−.026*	−.003*	.000	.000
Running memory—letters	−.018*	.001	.003	.002
Running Memory—positions	−.025*	−.008*	−.005*	−.006*

Note: PF1, first unrotated principal factor.
$^*p < .01$.

WMS IV test batteries. That is, the median age correlation was −.44 when the measures were considered alone, but the median was only .02 after controlling the variance in an estimate of general cognition. Many other studies over the past 25 years have also reported substantial relations of age on a general factor (e.g., Anstey et al., 2001; Hultsch, Hertzog, Dixon, & Small, 1998; Lindenberger, Mayr, & Kliegl, 1993; McArdle & Prescott, 1992; Park et al., 2002; Salthouse 2009; Salthouse & Czaja, 2000; Verhaeghen & Salthouse, 1997). In nearly every case, the associations with age on the target measures were substantially reduced when the measures were examined after statistically holding constant variance shared among different cognitive measures. The frequency of findings such as these has inspired the following comments:

> …the data showing that there are shared age-related influences are monumental and diverse. (Deary, 2000, p. 260)
>
> … the common finding of shared age effects is so well established that it has attained the status of an empirical benchmark that any sufficient theory of cognitive aging must explain (or at least accommodate) …. (Sliwinski, Hofer, & Hall, 2003, p. 672)

Because age differences on different target measures can vary in magnitude, perhaps as manifested in the form of an interaction of condition and measure in an analysis of variance, the age-related effects are sometimes assumed to be specific for certain cognitive measures. However, it is important to distinguish differential magnitude from uniqueness of age relations when referring to age-related effects (e.g., Salthouse & Coon, 1994; Salthouse, Toth, Hancock, & Woodard, 1997). That is, the critical question from an individual differences perspective is not whether age relations on different target measures vary in magnitude, because this could occur for variety of reasons, such as variation in reliability, or differential dependence on a common resource or factor. Instead, the relevant issue is whether the age relations on the target measure are unique to that measure and statistically independent of the age relations on other measures. Information of this type is only available when the target measure is analyzed in the context of other cognitive measures obtained from the same individuals.

A considerable amount of evidence now exists suggesting that only some of the adult age differences observed in any given cognitive measure are unique to that measure, with most of the differences reflecting influences shared with other cognitive measures. Instead of treating cognitive measures as if they exist in isolation, therefore, these findings imply that it may be reasonable, following a suggestion by Salthouse (1992), to reconceptualize the null hypothesis in research on aging and cognition from “no age differences” to “no age differences beyond those shared with other cognitive abilities.”

Interim summary. Results from several different types of analytical procedures indicate that very small proportions of the cross-sectional age-related effects on a variety of cognitive measures are independent of broader influences shared among different cognitive measures. Although many questions remain about this type of research, the available findings imply that it may not be meaningful to interpret the age relations on a target measure exclusively in terms of task-specific mechanisms such as strategy, processing component, or activation in a discrete neuroanatomical region, unless age-related influences shared with other cognitive measures have been taken into consideration.

Conclusion

The individual differences approach has roots in some of the earliest studies in cognitive aging, and much of the rapid growth utilizing this perspective since the 1960s can be traced to pioneering research by John Horn, Warner Schaie, and their colleagues. The major focus of this article was on three contemporary contributions of the individual differences approach that have evolved from these early studies: (a) enhancing quality of measurement and investigating equivalence of meaning at different ages; (b) facilitating the interpretation of measures by specifying how different cognitive measures are related to one another, and to age; and (c) distinguishing shared and unique age-related influences on target measures.

In order to capitalize on these potential contributions of the individual differences perspective, three recommendations can be proposed for future research. The first is to obtain multiple measures of the relevant construct instead of relying on a single measure and assuming a one-to-one correspondence between measure and construct. The second suggestion is to administer a battery of cognitive tests representing major cognitive abilities in addition to the tasks of primary interest to allow general influences to be evaluated and distinguished from specific influences. A final recommendation is to employ larger samples of participants to allow powerful analyses of correlations that are fundamental in research focusing on individual differences. Although they will add to the cost and complexity of research, implementation of these suggestions may allow the meaning of measures, and equivalence of meaning across age and time, to be investigated; provide information about the context in which the relations between age and the target measure are embedded; and determine the extent to which age-related effects on target measures are unique and independent of age-related effects on other cognitive measures.

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References

Anstey, K. J., Luszcz, M. A., & Sanchez, L. (2001). A reevaluation of the common factor theory of shared variance among age, sensory function, and cognitive function in older adults. *Journal of Gerontology: Psychological Sciences*, **56B**, P3–P11. doi:10.1093/geronb/56.1.P3

Bilash, I. & Zubek, J. P. (1960). The effects of age on factorially "pure" mental abilities. *Journal of Gerontology*, **15**, 175–182. doi:10.1093/geronj/15.2.175

Birren, J. E. & Morrison, D. F. (1961). Analysis of the WAIS subtests in relation to age and education. *Journal of Gerontology*, **16**, 363–369. doi:10.1093/geronj/16.4.363

Brickley, P. G., Keith, T. Z., & Wolfle, L. M. (1995). The three-stratum theory of cognitive abilities: Test of the structure of intellect across the adult life span. *Intelligence*, **20**, 309–328. doi:10/1016/0160-2896(95)90013-6

Bromley, D. B. (1956). Some experimental tests of the effect of age on creative intellectual output. *Journal of Gerontology*, **11**, 74–82. doi:10.1093/geronj/11.1.74

Bromley, D. B. (1958). Some effects of age on short term learning and remembering. *Journal of Gerontology*, **13**, 398–406. doi:10.1093/geronj/13.4.398

Bromley, D. B. (1967). Age and sex differences in the serial production of creative conceptual responses. *Journal of Gerontology*, **22**, 32–42.

Carroll, J. B. (1993). *Human cognitive abilities*. New York, NY: Cambridge University Press. doi:10.1017/CBO9780511571312

Craik, F. I. M. (1968). Two components of free recall. *Journal of Verbal Learning and Verbal Behavior*, **7**, 996–1004. doi:10.1016/S0022-5371(68)80058-1

Cronbach, L. J. (1957). The two disciplines of scientific psychology. *American Psychologist*, **12**, 671–684. doi:10.1037/h0043943

Cunningham, W. R. (1980). Age comparative factor analysis of ability variables in adulthood and old age. *Intelligence*, **4**, 133–149. doi:10.1016/0160-2896(80)90011-2

Deary, I. J. (2000). *Looking down on human intelligence: From psychometrics to the brain*. Oxford: Oxford University Press. doi:10.1093/acprof:oso/9780198524175.001.0001

Farrimond, T. (1967). Visual and authority performance variations with age: Some implications. *Australian Journal of Psychology*, **19**, 193–201. doi:10.1080/00049536708255578

Foster, J. C., & Taylor, G. A. (1920). The applicability of mental tests to persons over fifty years of age. *Journal of Applied Psychology*, **4**, 39–58. doi:/10.1037/h0071260

Gilbert, J. G., & Levee, R. E. (1971). Patterns of declining memory. *Journal of Gerontology*, **26**, 70–75. doi:10.1093/geronj/26.1.70

Gustafsson, J. -E. (1988). Hierarchical models of individual differences in cognitive abilities. In R. J. Sternberg (Ed.) *Advances in the psychology of human intelligence* (Vol. **4.**, pp. 35–71). Hillsdale, NJ: Erlbaum.

Horn, J. L. (1967). Organization of data on life-span development of human abilities. In L. R. Goulet & P. B. Baltes (Eds.), *Life-span developmental psychology: Research and theory*. (pp. 423–466). New York, NY: Academic Press.

Horn, J. L., Donaldson, G., & Engstrom, R. (1981). Apprehension, memory, and fluid intelligence decline in adulthood. *Research on Aging*, **3**, 33–84. doi:10.1177/016402758131002

Hultsch, D. F. (1969). Adult age differences in the organization of free recall. *Developmental Psychology*, **1**, 673–678. doi:10.1037/h0028271

Hultsch, D. F., Hertzog, C., Dixon, R. A., & Small, B. J. (1998). *Memory change in the aged*. New York, NY: Cambridge University Press.

Hultsch, D. F., Nesselroade, J. R., & Plemons, J. K. (1976). Learning-ability relations in adulthood. *Human Development*, **19**, 234–247. doi:10.1159/000271531

Jacoby, L. L. (1991). A process dissociation framework: Separating automatic and intentional uses of memory. *Journal of Memory and Language*, **30**, 513–541. doi:10.1016/0749-596X(91)90025-F

Jensen, A. R. (1998). *The g factor: The science of mental ability*. Westport, CT. Prager.

Jones, H. E., & Conrad, H. (1933). The growth and decline of intelligence: A study of a homogeneous group between the ages of ten and sixty. *Genetic Psychological Monographs*, **13**, 223–298.

Krueger, L. E., & Salthouse, T. A. (2011). Influence of cognitive abilities and age on word recall performance across trials and list segments. *American Journal of Psychology*, **124**, 291–300. doi:10.5406/amerjpsyc.124.3.0291

Lindenberger, U., Mayr, U., & Kliegl, R. (1993). Speed and intelligence in old age. *Psychology and Aging*, **8**, 207–220. doi:10.1037/0882-7974.8.2.207

McArdle, J. J., & Prescott, C. A. (1992). Age-based construct validation using structural equation modeling. *Experimental Aging Research*, **18**, 87–115. doi:10.1080/03610739208253915

Mittenberg, W., Seidenberg, M., O'Leary, D. S., & DiGiulio, D. V. (1989). Changes in cerebral functioning associated with normal aging. *Journal of Clinical and Experimental Neuropsychology*, **11**, 918–932. doi:10.1080/01688638908400945

Park, D. C., Lautenschlager, G., Hedden, T., Davidson, N. S., Smith, A. D., & Smith, P. K. (2002). Models of visuospatial and verbal memory across the adult life span. *Psychology and Aging*, **17**, 299–320. doi:10.1037/0882-7974.17.2.299

Parker, K. (1983). Factor analysis of the WAIS-R at nine age levels between 16 and 74 years. *Journal of Consulting and Clinical Psychology*, **51**, 302–308. doi:10.1037/0022-006X.51.2.302

Roediger, H. L., & McDermott, K. B. (1995). Creating false memories: Remembering words not presented in lists. *Journal of Experimental Psychology: Learning, Memory and Cognition*, **21**, 803–814. doi:10.1037/0278-7393.21.4.803

Ruch, F. L. (1934). The differentiative effects of age upon human learning. *Journal of General Psychology*, **11**, 261–285. doi:10.1080/00221309.1934.9917838

Salthouse, T. A. (1991). Mediation of adult age differences in cognition by reductions in working memory and speed of processing. *Psychological Science*, **2**, 179–183. doi:10.1111/j.1467–9280.1991.tb00127.x

Salthouse, T. A. (1992). Shifting levels of analysis in the investigation of cognitive aging. *Human Development*, **35**, 321–342. doi:10.1159/000277253

Salthouse, T. A. (1998). Independence of age-related influences on cognitive abilities across the life span. *Developmental Psychology*, **34**, 851–864. doi:10.1037/0012-1649.34.5.851

Salthouse, T. A. (2007). Implications of within-person variability in cognitive and neuropsychological functioning on the interpretation of change. *Neuropsychology*, **21**, 401–411. doi:10.1037/0894-4105.21.4.401

Salthouse, T. A. (2009). Decomposing age correlations on neuropsychological and cognitive variables. *Journal of the International Neuropsychological Society*, **15**, 650–661. doi:10.1017/S1355617709990385

Salthouse, T. A. (2011). What cognitive abilities are involved in trail-making performance? *Intelligence*, **39**, 222–232. doi:10.1016/j.intell.2011.03.001

Salthouse, T. A. (2014). Correlates of cognitive change. *Journal of Experimental Psychology. General*, **143**, 1026–1048. doi:10.1037/a0034847

Salthouse, T. A., & Coon, V. E. (1994). Interpretation of differential deficits: The case of aging and mental arithmetic. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, **20**, 1172–1182. doi:10.1037/0278-7393.20.5.1172

Salthouse, T. A., & Czaja, S. (2000). Structural constraints on process explanations in cognitive aging. *Psychology and Aging*, **15**, 44–55. doi:10.1037/0882-7974.15.1.44

Salthouse, T. A., & Davis, H. P. (2006). Organization of cognitive abilities and neuropsychological variables across the lifespan. *Developmental Review*, **26**, 31–54. doi:10.1016/j.dr.2005.09.001

Salthouse, T. A., & Ferrer-Caja, E. (2003). What needs to be explained to account for age-related effects on multiple cognitive variables? *Psychology and Aging*, **18**, 91–110. doi:10.1037/0882-7974.18.1.91

Salthouse, T. A., Pink, J. E., & Tucker-Drob, E. M. (2008). Contextual analysis of fluid intelligence. *Intelligence*, **36**, 464–486. doi:10.1016/j.intell.2007.10.003

Salthouse, T. A., & Siedlecki, K. L. (2007). An individual differences analysis of false recognition. *American Journal of Psychology*, **120**, 429–458. doi:10.2307/20445413

Salthouse, T. A., Siedlecki, K. L., & Krueger, L. E. (2006). An individual differences analysis of memory control. *Journal of Memory and Language*, **55**, 102–125. doi:10.1016/j.jml.2006.03.006

Salthouse, T. A., Toth, J. P., Hancock, H. E., & Woodard, J. L. (1997). Controlled and automatic forms of memory and attention: Process purity and the uniqueness of age-related influences. *Journal of Gerontology: Psychological Sciences*, **52B**, P216–P228. doi:10.1093/geronb/52B.5.P216

Schaie, K. W. (1958). Rigidity-flexibility and intelligence: A cross-sectional study of the adult life span from 20 to 70 years of age. *Psychological Monographs*, **72**, 9. doi:10.1037/h0093788

Schaie, K. W., Willis, S. L., Jay, G., & Chipuer, H. (1989). Structural invariance of cognitive abilities across the adult life span: A cross-sectional study. *Developmental Psychology*, **25**, 652–666. doi:10.1037/0012-1649.25.4.652

Schretlen, D., Pearlson, G. D., Anthony, J. C., Aylward, E. H., Augustine, A. M., Davis, A. & Barta, P. (2000). Elucidating the contributions of processing speed, executive ability, and frontal lobe volume to normal age-related differences in fluid intelligence. *Journal of the International Neuropsychological Society*, **6**, 52–61. doi:10.1017/S1355617700611062

Siedlecki, K. L., & Salthouse, T. A. (2014). Using contextual analysis to investigate the nature of spatial memory. *Psychonomic Bulletin & Review*, **21**, 721–727. doi:10.3758/s13423-013-0523-z

Sliwinski, M. J., Hofer, S. M., & Hall, C. (2003). Correlated and coupled change in older adults with and without preclinical dementia. *Psychology and Aging*, **18**, 672–683. doi:10.1037/0882-7974.18.4.672

Sudarshan, N. J., Bowden, S. C., Saklofske, D. H. & Weiss, L. G. (in press). Age-related invariance of abilities measured with the Wechsler Adult Intelligence Scale-IV. *Psychological Assessment*.

Sward, K. (1945). Age and mental ability in superior men. *American Journal of Psychology*, **58**, 443–479. doi:10.2307/1417762

Thorndike, E. L., Bregman, E. O., Tilton, J. W., & Woodyard, E. (1928). *Adult Learning*. New York, NY: The MacMillan Co.

Verhaeghen, P., & Salthouse, T. A. (1997). Meta-analyses of age-cognition relations in adulthood: Estimates of linear and non-linear age effects and structural models. *Psychological Bulletin*, **122**, 231–249. doi:10.1037/0033-2909.122.3.231

Widaman, K. F., Ferrer, E., & Conger, R. D. (2010). Factorial invariance within longitudinal structural equation models: Measuring the same construct across time. *Child Development*, **4**, 10–18. doi:10.1111/j.1750-8606.2009.00110.x