Developmental Psychology
2013, Vol. 49, No. 8, 1529–1543

© 2012 American Psychological Association
0012-1649/13/$12.00 DOI: 10.1037/a0030623

Stability and Change in Intelligence From Age 12 to Age 52: Results From the Luxembourg MAGRIP Study

Daniela Schalke
Research Center for Educational Measurement and Applied Cognitive Science, University of Luxembourg

Martin Brunner
Free University of Berlin and the Berlin-Brandenburg Institute for School Quality

Christian Geiser
Utah State University

Franzis Preckel
University of Trier

Ulrich Keller, Marion Spengler, and Romain Martin
Research Center for Educational Measurement and Applied Cognitive Science, University of Luxembourg

The present longitudinal study tackled 2 key aspects of the development of intelligence across a 40-year time period from age 12 to age 52 concerning (a) stability and change in the structure of intelligence with reference to the age differentiation-dedifferentiation hypothesis (how different cognitive abilities relate to each other across age) and (b) differential stabilities (the rank ordering of persons' intelligence levels across time). To this end, we drew on 2 structural conceptions of intelligence: (a) the extended Gf-Gc model to study broad cognitive abilities and (b) the 3-stratum model to decompose cognitive change into processes that are shared by all broad abilities (attributable to general cognitive ability *g*) and processes specific to a certain ability (independent of *g*). Data were obtained for 344 persons (56.4% female). The results showed that people differ more greatly over time with respect to all broad abilities except for fluid reasoning, whereas the rank ordering of persons on all broad abilities remains remarkably stable. These combined results yielded substantial gap-widening effects from age 12 to age 52 years that were mainly accounted for by a substantial increase in *g* variance in combination with a high differential stability of *g*. Moreover, the increase in *g* variance reflects an increase in covariance among different broad abilities, which indicates that the different constructs relate more closely to each other at age 52 compared to age 12 (i.e., age dedifferentiation). Two theoretical explanations of this change in the structure of intelligence are discussed (common cause hypothesis and investment theory).

Keywords: differentiation, dedifferentiation, intelligence, differential stability, investment theory

Supplemental materials: http://dx.doi.org/10.1037/a0030623.supp

Stability and change in intelligence across the lifespan are crucial topics in human development because intelligence is of great importance for facing challenges at school, at work, and in everyday life (Gottfredson, 1997). To profoundly understand the developmental dynamics of cognitive aging, it is essential to study longitudinal data that extend from childhood to adulthood, where the same individuals take the same cognitive measures two or more times (Schaie & Hofer, 2001). There are a number of longitudinal studies that have tackled the developmental dynamics of cognitive abilities from early adulthood to old age, such as the Seattle Longitudinal Study (Schaie, 2005); in very old individuals, such as the Berlin Aging Study (Baltes & Lindenberger, 1997); and from late childhood into old age, such as the Scottish Mental Survey (Deary, Whalley, Lemmon, Crawford, & Starr, 2000; Deary, Whiteman, Starr, Whalley, & Fox, 2004; see Schaie & Hofer, 2001, for a review of other longitudinal studies). However, little is known about the developmental dynamics of cognitive abilities from late childhood to middle adulthood. Thus, the present longitudinal study contributes to the existing body of research by investigating the change and stability of intelligence from late childhood (age 12 years) to middle adulthood (age 52 years). More specifically, we tackled two key aspects of lifespan intellectual development over a 40-year time period concerning (a) changes in the structure of intelligence embedded into the framework of the

---

Daniela Schalke, Research Center for Educational Measurement and Applied Cognitive Science, University of Luxembourg, Walferdange, Luxembourg; Martin Brunner, Educational Science and Psychology, Free University of Berlin and the Berlin-Brandenburg Institute for School Quality, Berlin, Germany; Christian Geiser, Department of Psychology, Utah State University; Franzis Preckel, Department of Psychology, University of Trier, Trier, Germany; Ulrich Keller, Marion Spengler, and Romain Martin, Research Center for Educational Measurement and Applied Cognitive Science, University of Luxembourg.

This study was supported by a grant from the Luxembourgish Fonds National de la Recherche (VIVRE—Living tomorrow in Luxembourg, Project No. FNR/06/09/18) and a PhD scholarship awarded to Daniela Schalke by the Fonds National de la Recherche.

Correspondence concerning this article should be addressed to Daniela Schalke, University of Luxembourg, Center for Educational Measurement and Applied Cognitive Science (EMACS), Campus Walferdange, L-7220 Walferdange, Luxembourg. E-mail: daniela.schalke@uni.lu

age differentiation-dedifferentiation hypothesis and (b) differential stabilities, that is, the rank ordering of persons' intelligence levels across age.

Conceptualization and Structure of Intelligence

Intelligence can be conceptually defined as "a very general mental capability that, among other things, involves the ability to reason, plan, solve problems, think abstractly, comprehend complex ideas, learn quickly and learn from experience" (Gottfredson, 1997, p. 13). Most current psychological research is based on the psychometric approach (Neisser et al., 1996), which states that intelligence is well measured by tests, and individual differences on these tests are well represented by structural models (Gottfredson & Saklofske, 2009). These structural models (in terms of confirmatory or exploratory factor analytic models) are of central importance because they provide the starting point for relating intelligence to other theoretical concepts and for studying cognitive change (Edwards & Bagozzi, 2000).

An important distinction has to be made between the statistical structure of intelligence and the theoretical interpretation of this structure (Kan, Kievit, Dolan, & van der Maas, 2011). Statistically, the common factors in factor models of intelligence capture the shared variance of the observed test scores and a theoretical framework is needed in order to interpret these factors. Whereas it is widely agreed that intelligence is hierarchically structured with constructs varying in their levels of generality, theories of intelligence differ in their conceptions of how broadly these constructs are defined and how many hierarchical levels are needed (Carroll, 1993; Cattell, 1987). Nevertheless, the similarities of different theories are so apparent that McGrew (2009) recently proposed the Cattell-Horn-Carroll (CHC) model of intelligence and thereby synthesized the two most prominent theories in the field: (a) the extended Cattell-Horn theory of fluid and crystallized intelligence (Cattell, 1987; J. L. Horn & Noll, 1997) and (b) Carroll's three-stratum theory (Carroll, 1993). The CHC model (McGrew, 2009) specifies a large number of primary abilities at the first level of the hierarchy. On the second level, primary abilities that rely on the same cognitive demands are structured into a system of 10 broad abilities. These broad abilities (for a description of the abilities that we examined in the present study, see Table 1) have been reproduced in several studies, and their discriminant validity has been shown (Carroll, 1993; J. L. Horn & McArdle, 2007; J. L. Horn & Noll, 1997). At the apex of the hierarchy in the CHC model is a general factor of intelligence, namely *g*, which accounts for the positive intercorrelations of the broad ability factors.

Even though the CHC model offers an integrating taxonomy for the similarities of the two underlying models, the extended Gf-Gc and the three-stratum model differ crucially with regard to the nature of *g*: Carroll (1993) interpreted *g* as a unique cognitive ability, whereas Horn argued strongly against the existence of *g* (compare J. L. Horn & McArdle, 2007; J. L. Horn & Noll, 1997). Interestingly, theories that accept or do not accept the existence of *g* have been used for different research purposes. *g* theories dominate studies investigating the predictive powers of cognitive capacities where *g* has been empirically demonstrated to predict a number of key life outcomes such as educational achievement (Strenze, 2007), occupational success (Schmidt & Hunter, 2004),

Table 1
Definitions of Abilities and Descriptions of Corresponding Measures as Applied in the Present Study

Broad ability	Measure	Description
Fluid reasoning (Gf) describes "the use of deliberate and controlled mental operations to solve novel problems that cannot be performed automatically. . . . Inductive and deductive reasoning are generally considered the hallmark indicators of Gf."	Concept Formation (*Gf_1*)	Identify, categorize, and determine rules from a complete stimulus set of patterns.
	Number and Letter Series (*Gf_2*)	Identify, categorize, and determine rules from a complete stimulus set of numbers and letters.
Comprehension-knowledge (Gc) "is typically described as a person's breadth and depth of acquired knowledge of the language, information, and concepts of a specific culture, and/or the application of this knowledge."	Vocabulary (*Gc_1*)	Identify the spelling error of a given noun.
	Word Identification (*Gc_2*)	Identify a word out of a random composition of letters.
Visual processing (Gv) "is the ability to generate, store, retrieve, and transform visual images and sensations."	Mental Figure Folding (*Gv_1*)	Identify the same position of a marker point on the layout and the folded object.
	Spatial Relations (*Gv_2*)	Identify the number of all hidden and unhidden surfaces of an object.
Processing speed (Gs) is "the ability to automatically and fluently perform relatively easy or over-learned elementary cognitive tasks, especially when high mental efficiency (i.e., attention and focused concentration) is required."	Perception Speed (*Gs_1*)	Quickly count all target objects and circle each eighth target object.
	Accuracy (*Gs_2*)	Quickly and accurately compare two rows that should be identical and find the error in the right row.

Note. Definitions are adopted from McGrew (2009, pp. 5 and 6).

and longevity (Gottfredson & Deary, 2004). However, *g* theories have rarely been used in developmental research (Ackerman & Lohman, 2003), as "the description of a cognitive system with only a single *g* factor is an overly simplistic view of the more complex sequential dynamics" (McArdle, Ferrer-Caja, Hamagami, & Woodcock, 2002, p. 134). Thus, in developmental research two-component theories such as the extended Gf-Gc theory have been prevailing (Lindenberger, 2001). These theories focus on the interplay and differences between fluid and crystallized abilities but not on *g*. However, we think that a comprehensive study of age-related changes in the structure of intelligence should examine both broad abilities *and g*. Hence, in the current study, we scrutinized the change and stability of intelligence by capitalizing on (a) the extended Gf-Gc model (see Figure 1a) and (b) the three-stratum model (see Figure 1b). Importantly, these two theories differ not only in their structural conceptualization of intelligence, but they may also highlight different aspects of change. Specifically, a first-order model like the extended Gf-Gc model allows examination of change in broad abilities and their intercorrelations. *g* captures these intercorrelations in a higher order model like the three-stratum model, and the different abilities statistically represent residual factors where the influence of *g* is partialled out (Brunner, Nagy, & Wilhelm, 2012). These residual factors capture only what is specific to each ability and are referred to as $Gf_{specific}$, $Gc_{specific}$, $Gv_{specific}$, and $Gs_{specific}$ in the model. Hence, a higher order model allows separating change specific to each ability from change shared by all abilities, captured by *g*.

In the current study, we focus on the developmental dynamics of four broad abilities: fluid reasoning (*Gf*), visual processing (*Gv*), processing speed (*Gs*), and comprehension-knowledge (*Gc*). Gf and Gc resemble the two opposing ends of abilities in two-component theories of intelligence, namely, fluid and crystallized abilities (Li et al., 2004). Moreover, Gv has shown incremental validity in predicting educational and vocational attainment (Shea, Lubinski, & Benbow, 2001), and Gs has been shown to play an important role in the development of cognitive abilities (Salthouse, 1996).

The Distinction Between Fluid and Crystallized Abilities

According to Li and Baltes (2006), three kinds of influences and their interactions affect cognitive development: (a) biological processes, (b) normative environmental processes (e.g., formal education), and (c) non-normative person-specific experiences that result from self-selection into different environments. However, some broad abilities may be more sensitive to the environment than others. For example, the extended Gf-Gc theory allocates broad abilities on a continuum between two poles (Cattell, 1987; Li et al., 2004): fluid abilities (e.g., Gf, Gv, Gs), which are more strongly based on biological processes, and crystallized abilities (e.g., Gc), which are to a larger extent influenced by the environment. As people age, environmental influences, especially person-specific experiences, accumulate and should result in increased individual differences between persons. However, this increase in variance should be more pronounced for crystallized than for fluid abilities. Moreover, because fluid and crystallized abilities are predicted to be influenced differently by biological processes (e.g., aging) and the environment, crystallized abilities decline less and later in life compared to fluid abilities (McArdle et al., 2002; Schaie, 2005; Tucker-Drob, 2009).

The Age Differentiation-Dedifferentiation Hypothesis

One of the most comprehensive hypotheses regarding the development of intelligence is the age differentiation-dedifferentiation hypothesis that postulates three developmental stages across the lifespan (Baltes, Cornelius, Spiro, Nesselroade, & Willis, 1980). The first stage of *differentiation* occurs during maturation but especially in early childhood when different broad abilities are proposed to become increasingly independent of each other with increasing age (Deary et al., 1996). This effect is statistically represented by a decline in intercorrelations among broad abilities in the extended Gf-Gc model (Deary et al., 2004) or a progressively decreasing role of the influence of *g* in the three-stratum model (Escorial, Juan-Espinosa, García, Rebollo, & Colom, 2003). The following time of adulthood is described as a stage of *stability* in the structure of intelligence (Baltes et al., 1980). The third stage of *dedifferentiation* is characterized by again increasing dependencies among different broad abilities as people reach old age (Baltes et al., 1980). This effect is statistically represented by increases in intercorrelations among broad abilities in the extended Gf-Gc model (Deary et al., 2004) or an increasing influence of *g* in the three-stratum model (Escorial et al., 2003).

Theoretical Accounts of Age Differentiation-Dedifferentiation

Theoretical accounts refer to the differential impact of biological and environmental influences on fluid and crystallized abilities as well as their interdependencies. Specifically, Cattell's investment theory (Cattell, 1987) postulates that fluid abilities are invested into the acquisition of crystallized abilities by taking advantage of environmental learning opportunities. When the environment becomes more heterogeneous as life unfolds, so do crystallized but not fluid abilities because crystallized abilities are more strongly impacted by the environment. This in turn leads to a differentiation of fluid and crystallized abilities. Lifespan developmental psychology has built upon these ideas and proposed comparable mechanisms for dedifferentiation in old age (Baltes & Lindenberger, 1997; Li & Baltes, 2006). At this stage, biological influences regain in importance by restricting cognitive performance in fluid abilities (Lindenberger & von Oertzen, 2006). Comparable to investment theory, declines in fluid abilities limit the acquisition or expression of crystallized abilities and, hence, the two broad categories of cognitive functioning grow closer together again (i.e., common cause hypothesis; Baltes & Lindenberger, 1997). However, some empirical findings point to qualitatively different processes that operate during maturation and senescence (Hommel, Li, & Li, 2004) so that they cannot simply be interpreted as the reverse of each other (Li & Baltes, 2006; Li et al., 2004).

Empirical Results on Age Differentiation-Dedifferentiation

The empirical results for the age-dependent differentiation-dedifferentiation are mixed (see Tucker-Drob & Salthouse, 2008, and; Zelinski & Lewis, 2003, for a good overview of

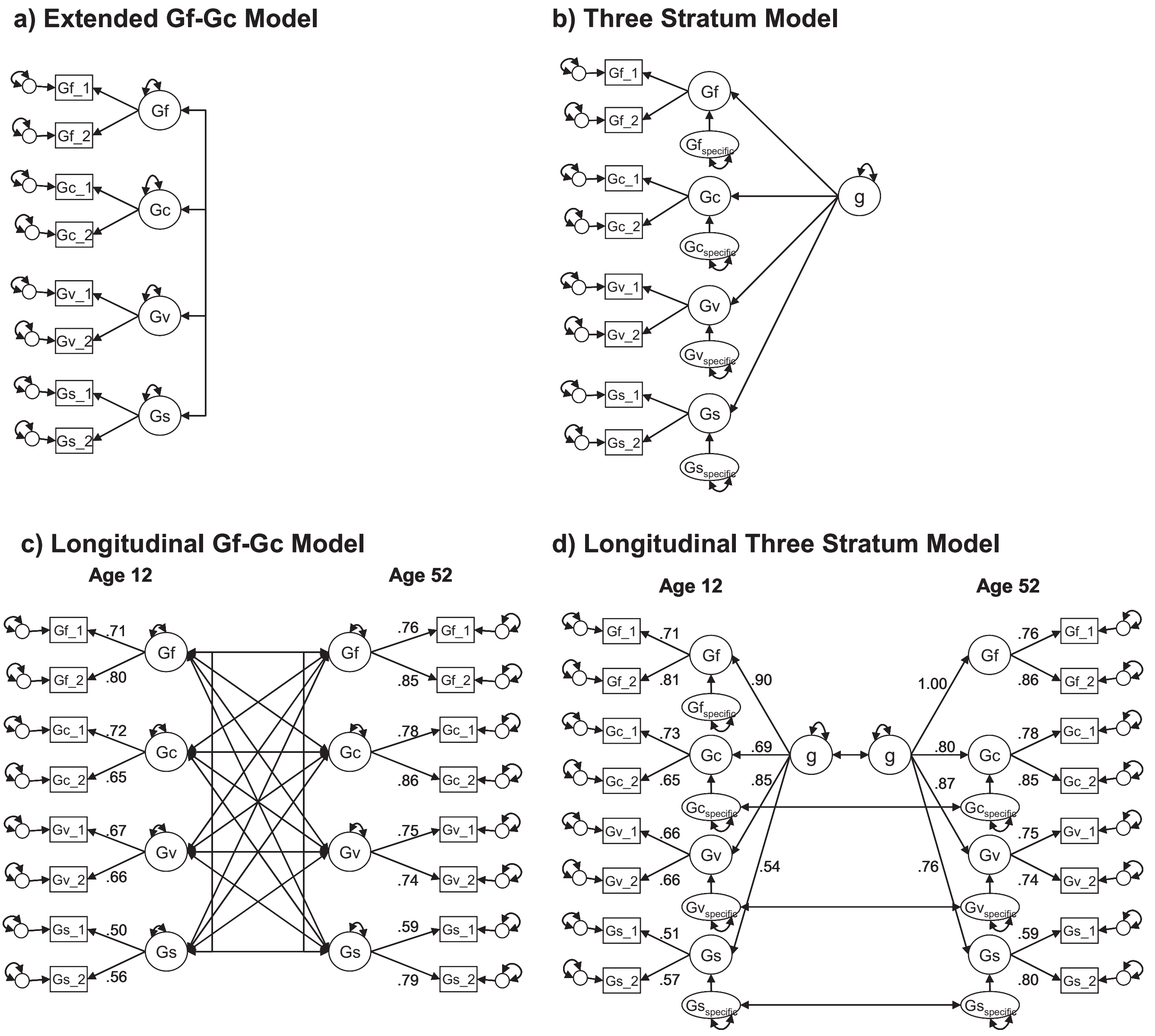

Figure 1. Alternative structural conceptualizations of intelligence. a. first-order factor model, representing the extended Gf-Gc model. b. Higher order factor model, representing the three-stratum model. c. Longitudinal extension of the extended Gf-Gc model. d. Longitudinal extension of the three-stratum model. Models c and d show the standardized factor loadings as obtained from Model T1.6 for the extended Gf-Gc model and Model C.3 for the three-stratum model. Gf = fluid reasoning; Gc = comprehension-knowledge; Gv = visual processing; Gs = processing speed; *g* = general cognitive ability. In b and d, the suffix *specific* indicates specific abilities from which the influence of *g* was partialled out. Squares represent manifest test scores, circles represent latent variables; one-headed asymmetrical arrows represent directional regression coefficients (factor loadings), whereas two-headed symmetrical arrows represent variances or covariances. Correlated uniqueness terms of the manifest indicators Gc_1, Gv_2, Gs_1, and Gs_2 in the longitudinally extended models are not shown to ensure clarity of presentation.

additional studies). For instance, support was found in cross-sectional comparisons by Baltes and Lindenberger (1997); Deary et al. (2004); Hayslip and Sterns (1979); Li et al. (2004), as well as longitudinal studies by Ghisletta and colleagues (Ghisletta & De Ribaupierre, 2005; Ghisletta & Lindenberger, 2003). By contrast, no support was found in cross-sectional studies by Escorial et al. (2003); Molenaar, Dolan, Wicherts, and van der Maas (2010); Tucker-Drob (2009); and Tucker-Drob and Salthouse (2008), or in longitudinal studies by Zelinski and Lewis (2003) and Schaie, Maitland, Willis, and Intrieri

(1998). This leads to the conclusion that, still, little is known about the age level at which differentiation and dedifferentiation actually occurs or whether the effects exist at all.

Problems in the Study of the Age Differentiation-Dedifferentiation Hypothesis

To some extent, these mixed findings may be attributed to a number of methodological challenges. First, studies have applied different ability measures and/or have used samples that differed in their composition and age, which may render the findings somewhat incomparable (Lindenberger & von Oertzen, 2006). Second, the operationalization of the age variable in the analyses poses a problematic question (Molenaar et al., 2010). Combining different age levels into one age group and dividing the sample into, respectively, younger and older age groups, categorizes a continuous variable and is problematic because little is known about the age level at which differentiation and dedifferentiation occurs. Third, the effect can be conceptualized in a number of different ways. Some studies have contrasted the proportion of variance accounted for by the first unrotated principal component (Li et al., 2004) or the (mean) subtest correlations among two or more age groups (Deary et al., 2004). However, these approaches reveal little as to where in the model an increase (decrease) in correlations among different broad abilities originates and thus preclude a better understanding of the effect. Others have tested the factor structure of different age groups by casting constraints on factor covariances, variances, and/or loadings (Zelinski & Lewis, 2003). This approach is much more specific, but it does not solve the problem of categorizing the age variable. Only a few studies have analyzed the effect within a structural equation modeling approach by casting explicit age constraints on the parameters of the model (Tucker-Drob, 2009; Tucker-Drob & Salthouse, 2008) or by using age-moderated factor analysis (Molenaar et al., 2010).

Differential Stabilities

Age-dependent differentiation-dedifferentiation concerns the stability and change in the structure of intelligence; that is, whether and to what extent ability constructs operate similarly across time. A second key aspect regarding the developmental dynamics of cognitive abilities concerns differential stabilities; that is, whether the rank ordering of individuals remains stable across time. Statistically, this is represented by the autocorrelation of cognitive abilities across time, which requires longitudinal data. The existing findings suggest that *g* shows high differential stability across the lifespan. An extensive review of studies that have examined the differential stability of *g* can be found in Conley (1984) or Deary et al. (2000). For example, Deary et al. (2000, 2004) reported differential stability estimates across almost the entire lifespan from age 11 to age 77 years as well as age 11 to age 80 years, with correlation coefficients (not corrected for measurement error) of $r = .63$ and $r = .66$, respectively. Hertzog and Schaie (1986) analyzed differential stability by means of a *g*-factor spanning an age range of 20 to 74 years at the first test session, over a time span of 14 years. They found differential stability estimates for *g* that were corrected for measurement error of $r = .92$ for the whole age sample as well as comparable correlations when they divided their sample into three age groups (young $r = .93$, middle age $r = .96$, old age $r = .89$).

Only a few studies have addressed differential stabilities of different broad abilities over long time periods. The results of some key studies indicate comparable differential stabilities for broad abilities as were found for *g* (for a summary see Table S1 in the online supplemental materials). However, some studies have found higher differential stabilities for crystallized than for fluid abilities (Eichorn, Hunt, & Honzik, 1981; Gold et al., 1995; Kangas & Bradway, 1971; Nisbet, 1957; Owens, 1966; Schwartzman, Gold, Andres, Arbuckle, & Chaikelson, 1987), but others have not (Larsen, Hartmann, & Nyborg, 2008; Schaie & Strother, 1968; Tuddenham, Blumenkrantz, & Wilkin, 1968). Interestingly, Larsen et al. (2008) found a vast decrease in differential stabilities of both verbal and arithmetic reasoning from $r = .82$ and .79 to $r = .44$ and .36, respectively, after the influence of *g* had been partialled out. This indicates that a large proportion of the differential stabilities of broad abilities (as represented by first-order factors) may be attributed to the differential stability of *g*. Hence, the rank ordering of specific abilities may be subjected to change to a larger degree than *g*. However, this conclusion is tentative because, to our knowledge, the study by Larsen et al. (2008) was the only study that took the stability of *g* into account when studying the differential stabilities of (specific) abilities.

However, previous findings on differential stabilities (see Table S1) should be interpreted with some caution for two reasons. First, there are only a few longitudinal studies that have used latent variables that are free of measurement error. Hence, the reported results may underestimate the true differential stabilities because the stabilities reported for manifest test scores are attenuated by measurement error. Second, the differential stabilities of broad abilities (e.g., in a first-order model) may be overestimated because they do not separate the stability of *g* from the stabilities of broad abilities. Consequently, the differential stabilities of specific abilities as conceptualized in terms of a higher order model may be somewhat lower.

Methodological Requirements—Measurement Invariance

According to T. D. Little (1997), two types of measurement invariance (MI) can be distinguished: Type 1 MI concerns properties of the measurement scale (i.e., the measurement part of a model) across time, and Type 2 MI concerns latent variances, covariances, and means (i.e., the structural part of a model) across time. Type 1 invariance of measurement properties is needed in order to make meaningful comparisons of any latent construct in the intelligence models described above across time (age) by separating true changes in latent abilities from changes in operational definitions of the constructs. Thus, we first have to ensure that the measured (sub)tests relate to the latent common factors in the same way at all times of measurement (Meredith & Horn, 2001). More specifically, Type 1 MI concerns four different properties of the measurement scale (Cheung & Rensvold, 2002). First, *configural invariance* requires that the pattern of zero and nonzero loadings of observed indicators on the common factors remain the same across time. Second, *metric invariance* requires invariant factor loadings across time (i.e., the magnitudes of the unstandardized factor loadings have to be equal at all measurement occasions) and allows for the application of meaningful analyses of correlations and variances across time (Lubke, Dolan, Kelderman, &

Mellenbergh, 2003). Third, *error invariance* requires the residual variances of the observed indicators (unique indicator variance and measurement error variance) to be invariant across time to ensure that the indicators are measured with the same amount of precision. A lack of error invariance may complicate the meaningful interpretation of latent variances, covariances, and means, even when other invariance constraints are tenable (DeShon, 2004). Fourth, *scalar invariance* requires time-invariant intercepts and is needed for a meaningful comparison of means. J. L. Horn, McArdle, and Mason (1983) questioned whether even metric invariance can realistically be expected in complex data sets used in developmental studies. However, some studies have shown that cognitive measures can demonstrate metric invariance across several age groups (for an overview, see Zelinski & Lewis, 2003).

Type 1 MI is important and necessary but only a prerequisite for studying so-called Type 2 differences in latent variances, covariances, and means (Cheung & Rensvold, 2002; T. D. Little, 1997). Crucially, the Type 2 differences represent the substantive research interest in the present study because changes across time in the covariances and variances of the latent broad abilities directly tackle age differentiation-dedifferentiation. Remember that the hypothesis postulates changes in intercorrelations of different broad abilities across life stages. In a first-order model, such as the extended Gf-Gc model, changes in correlations among broad abilities can be caused by changes in covariances and/or changes in variances because a correlation between two broad abilities is computed by dividing their covariance by the product of their standard deviations. In a higher order model, such as the three-stratum model, a change in the intelligence structure is captured by changes in the variance of specific abilities and *g*, as well as second-order factor loadings of the different ability constructs on *g*.

The Present Study

The present study tackles two key aspects of the developmental dynamics of cognitive abilities concerning (a) stability and change in the structure of intelligence with reference to the age differentiation-dedifferentiation hypothesis and (b) differential stabilities across a 40-year time period from late childhood (at age 12) into middle adulthood (at age 52). A vital feature of the present study is that we examined these developmental dynamics by means of two alternative structural conceptualizations of intelligence: (a) the extended Cattell-Horn Gf-Gc model (Cattell, 1987; J. L. Horn & Noll, 1997) and (b) Carroll's three-stratum model (Carroll, 1993). Most previous developmental studies have conceptualized intelligence by applying two-component models, such as the extended Gf-Gc model, whereas psychometric research has been dominated by theoretical models that include *g*, such as Carroll's three-stratum model. Crucially, each model highlights different aspects of the data that are not visible from the vantage point of the other model. In particular, the extended Gf-Gc model emphasizes change in broad abilities as a whole, whereas the three-stratum model divides this change into change that is specific to each ability and change shared by all abilities and thus captured by *g*.

Drawing on these alternative conceptualizations of intelligence, the present longitudinal study makes several important contributions to the empirical body of research on the developmental dynamics of cognitive abilities. (a) It spans 40 years from late childhood to middle adulthood. Previous longitudinal studies on child development have rarely looked at intelligence development beyond early adulthood, and most of the developmental research on adults focuses on old age but not on middle adulthood. Hence, the present study provides vital information on cognitive development for an age range for which little empirical knowledge exists. (b) Previous results on the age differentiation-dedifferentiation hypothesis were mixed, and still little is known about the differentiation and dedifferentiation of the structure of cognitive abilities from late childhood to middle adulthood. Crucially, and in contrast to most previous research, we studied these processes across 40 years of people's lifetimes by means of a longitudinal sample that is highly homogeneous with respect to age. Moreover, as most previous developmental research on this hypothesis was embedded in the extended Gf-Gc model, it is not clear whether changes in the structure of intelligence can be attributed to a common core in terms of *g* or whether these changes are limited to specific abilities. (c) Most previous research on the differential stability of intelligence was conducted on the manifest level and therefore did not control for changes in the operational definition of the construct or for measurement error. Moreover, previous research mostly drew on the extended Gf-Gc model. Thus, little is known about the differential stability of specific abilities after the influence of *g* has been accounted for. Taken together, the current study provides a more detailed picture of the developmental dynamics of cognitive abilities for the time span from late childhood (at age 12) into middle adulthood (at age 52) by disentangling change that is attributed to specific abilities from change that is attributable to *g*.

Method

Participants and Procedure

The current longitudinal study (entitled MAGRIP) covers a time span of 40 years and encompasses two points of measurement: 1968 and 2008. In 1968, a multistage sampling procedure was applied to create two (overlapping) representative samples. First, half of all Grade 6 school classes in Luxembourg were selected randomly. All students from these classes participated. This sample is representative of sixth graders in Luxembourg. Second, a representative age-based sample was drawn that included all students in the selected schools who were enrolled in school in the school year 1963–1964. These were students who attended classes spanning from Grades 3 to 6 (students in lower grades had repeated one or more classes). To control for differential effects of age on cognitive development, we drew from this age-based sample, which included 2,450 children[1] (50.0% female), who were about 12 years old ($M = 11.7$ years, $SD = 3.8$ months) at the time of testing. All children completed a comprehensive intelligence test, the *Leistungsprüfsystem* (i.e., achievement test battery; W. Horn, 1962, 1983), which was administered by trained university students in a group setting.

In 2008, a sample that was stratified by region of residence in 1968 and gender of 344 (56.4% female) of these former students

---

[1] One student was excluded because of severe outlying values on one of the intelligence subtests.

retook the same intelligence test at about 52 years of age. About two thirds of the retested age based sample ($n = 227$) took this test in a group setting; the remaining participants were visited at home to take the test individually. All tests were administered by trained assessors, and the test-taking procedure strictly followed the standardization of the test manual. Estimates of selective attrition of the retested age based sample show that (relative to the age base sample in 1968), the people who participated at both waves of measurement were slightly positively selected with respect to mean childhood *g* (Cohen's $d = 0.34$), parental socioeconomic status ($d = 0.08$), and grade point average (i.e., the mean grades computed across the last four trimesters prior to data collection in 1968; $d = 0.28$). Additional information on selective attrition of the retested age based sample is depicted in Table S2 in the online supplemental materials (for a detailed overview of the data collection stages and attrition, see Figure S1 in the online supplemental materials).

Measures

Intelligence at ages 12 and 52 years was assessed by nine subtests taken from a standardized and well validated German intelligence test battery, named the *Leistungsprüfsystem* (L-P-S; i.e., achievement test battery; W. Horn, 1962, 1983). Gf, Gv, and Gs were each assessed with two subtests. Gc was captured by three subtests. Each subtest contained 40 items and had to be completed within strict time constraints that were specified in the test manual. Because two of the three subtests of Gc contained the same kinds of items, we merged the scores on these two subtests into a single composite score to avoid having variance specific to this kind of subtest reflected in the factor Gc. Hence, every broad ability factor was assessed by two subtests, which are described in Table 1. Split-half reliabilities of single subtests, as reported in the L-P-S test manual, range between $r_{tt} = .89$ for the subtest Gs_1 and $r_{tt} = .97$ for subtest Gc_2 (Sturm, Willmes, & Horn, 1993), as well as split-half reliabilities for scales range between $r_{tt} = .90$ for Gf and $r_{tt} = .99$ for Gs (W. Horn, 1983). Sturm and Büssing (1982) reported a correlation of .94 between the L-P-S total score and the total score on the German version of the Wechsler Adult Intelligence Scale (WAIS; Tewes, 1991; note that the online supplement contains detailed information on the reliability and validity of the L-P-S.) In 1968, the children were randomly administered one of two parallel test forms of the L-P-S. Because the means and variances of subtests differed slightly across test forms, we used a linear-conversion rule (Kolan & Brennan, 1995) to equate the test scores. To this end, we standardized the subscales separately for each test form to an IQ metric with a mean of 100 and an *SD* of 15 for the base sample. In 2008, the participants were given the exact same test form and items that they had completed in 1968. To allow meaningful comparisons across time, subtest scores obtained for the second wave of measurement in 2008 were equated by using the same conversion rules as applied in 1968 (i.e., the standardization of measures in 2008 was based on means and *SD*s obtained from the entire age based sample in 1968).

Statistical Analysis

Strategy of analyses. Longitudinal confirmatory factor analysis was used to test the age differentiation-dedifferentiation hypothesis as well as differential stabilities in both the extended Gf-Gc and the three-stratum model. Some of the subtest scores were approximately but not strictly normally distributed. We therefore used maximum-likelihood estimation with robust standard errors (MLR) as implemented in the Mplus program (Mplus 6; Muthén & Muthén, 1998–2010). We conducted our main analyses in consecutive steps. In a first step, we tested for MI of the psychometric properties of the subtest scores (Type 1 MI) across age 12 and age 52. Because the three-stratum model rests on the extended Gf-Gc model, they share the same measurement model. Thus, the test for Type 1 MI applied to both models. To study Type 1 MI, we tested configural invariance first and metric invariance second. We then proceeded by testing the equality of error variances because these residual variances could also contain reliable unique sources of variance, and changes in the residual part of the model might complicate the substantial interpretation of factor variances and covariances, which were the main focus of the present study. We tested for scalar invariance last, as this level of Type 1 MI was least important for our hypotheses. To assess model fit we applied nested-model comparisons and consulted several fit indices that are recommended in the literature (see online supplement for details). In the second step of our analyses, we tested for Type 2 MI of latent variances, covariances, and factor loadings across time, which tackles the age differentiation-dedifferentiation hypothesis. Third, we assessed the differential stabilities of broad abilities, specific abilities, and *g*.

Handling correlated residual terms. A vexing problem of research on cognitive development is that an observed subtest score may not only capture the target ability construct(s) but also some unique ability that is specific to a certain subtest. The latter is represented by the subtests' residual terms in factor models (Brunner et al., 2012). Preliminary analyses showed that for some of the subtests (i.e., Gc_1_{12} with Gc_1_{52}, Gv_2_{12} with Gv_2_{52}, Gs_1_{12} with Gs_1_{52}, and Gs_2_{12} with Gs_2_{52}) the residual terms were significantly correlated across the two measurement occasions. As recommended in the literature for longitudinal studies (Cole & Maxwell, 2003), we therefore allowed the residual terms of these subtests to correlate across time in all models that we investigated.

Handling missing data. Missing values were not a severe problem in our data. For the 344 participants in the longitudinal sample, data were missing on one variable (Gv_1) for 11 participants on the other variables for only one or two participants. Full information maximum likelihood (FIML) estimation was used to handle missing data (R. J. A. Little & Rubin, 2002).

Results

Descriptive Statistics

The manifest scores of all indicators showed substantial mean increases across time with large effect sizes (ranging from $d = 0.52$ to $d = 2.71$; see Table 2). Furthermore, the correlations between the measures at age 12 and 52 ranged between $r = .40$ and .62, respectively, suggesting moderate to high differential stabilities of the observed subtest scores (see Table S3 in the online supplement for a full correlation matrix of all measures applied and information on reliabilities of subtest scores). Moreover, to measure changes in variance across time, we computed variance

Table 2
Mean Change, Differential Stability, and Change in Variability as Obtained for Observed Subtest Scores in the Longitudinal Sample

	Age 12		Age 52		Age 12 vs. age 52		
Measure	*M*	*SD*	*M*	*SD*	ES	*r*	Variance ratios
Comprehension-knowledge							
Gc_1	102.80	13.04	161.98	24.14	2.71	.62	3.43
Gc_2	103.11	14.68	133.63	21.13	1.63	.47	2.07
Fluid reasoning							
Gf_1	104.67	14.18	117.42	15.80	0.85	.48	1.24
Gf_2	104.86	13.02	121.76	13.83	1.26	.54	1.13
Visual processing							
Gv_1	103.51	15.34	112.52	18.91	0.52	.40	1.52
Gv_2	103.55	14.12	116.32	14.52	0.89	.57	1.06
Processing speed							
Gs_1	101.70	14.79	121.19	23.55	0.96	.40	2.53
Gs_2	102.22	12.99	121.95	17.40	1.27	.41	1.79

Note. ES = effect size for mean differences of correlated measures across time computed according to Dunlap, Cortina, Vaslow, and Burke (1996); *r* = differential stability; Variance ratios = variance at age 52/variance at age 12 (values larger than 1 indicate larger variability at age 52 compared to age 12); Gc = comprehension-knowledge; Gf = fluid reasoning; Gv = visual processing; Gs = processing speed; _1 and _2 refer to manifest variables 1 and 2 that measure the respective broad ability. *N* = 344, full information maximum likelihood estimates for missing data.

ratios by dividing the variance of a subtest score at age 52 by the variance of the same subtest score at age 12: A value of 1 indicates no change in variance, values greater and smaller than 1 indicate an increase or, respectively, decrease in variance at age 52. The variance ratios of subtest scores indicated that the variances for measures of Gc and Gs increased more than the variances for measures of Gf and Gv.

Invariance of Psychometric Properties of Subtest Scores Across Time

To study the Type 1 MI of subtest scores, we examined a series of increasingly constrained models. The key results of these analyses can be summarized as follows (see online supplement for a detailed description of these analyses and a report of model fit indices in Table S4). A partial scalar invariant measurement model (i.e., T1.6; see online supplement), where subtests demonstrated complete metric invariance of factor loadings, partial invariance of the residual terms (the residual variances of the subtest scores Gc_1 and Gs_1 were not invariant across time), and partial invariance of the intercepts (the intercepts of the subtests Gc_1 and Gv_1 were not invariant across time), provided a good fit to the data. The standardized factor loadings (λ) obtained for this model (see Figure 1c) show that each factor representing a broad ability was well defined with values ranging between $\lambda = .50$ (for the loading of Gs_1 on Gs at age 12) and $\lambda = .86$ (for the loading of Gc_2 on Gc at age 52). As noted above, the residual terms of some subtests were significantly correlated across the two measurement occasions, involving Gc_1with $r = .37$, Gv_2 with $r = .27$, Gs_1 with $r = .21$, and Gs_2 with $r = .26$. Note that these correlated uniqueness terms remained approximately the same when we tested the three-stratum model (see below). Model T1.6 also provides some insights into changes in latent means of broad abilities across time (a question that was, however, not central to the present article). We observed substantial and statistically significant increases in mean changes from age 12 to age 52 representing very large effect sizes[2]: $d_{Gf} = 1.34$, $d_{Gs} = 1.48$, $d_{Gv} = 1.16$, and $d_{Gc} = 1.58$. Note that the mean changes observed for Gc and Gv should be interpreted with caution as partial scalar invariance implies that mean changes in the (observed) subtest scores represent not only changes in the latent means of the corresponding broad abilities but also mean change attributable to subtest-specific abilities (see Millsap & Olivera-Aguilar, 2012). To conclude, our results concerning Type 1 MI indicate that the operational definition of the four broad abilities is fundamentally the same at age 12 and age 52 and allows meaningful comparisons of the latent covariances and variances in order to test the age differentiation-dedifferentiation hypothesis based on the extended Gf-Gc model and the three-stratum model, respectively.

Testing the Age Differentiation-Dedifferentiation Hypothesis

The extended Cattell-Horn Gf-Gc model. Model T1.6 reflects the structural propositions of the extended Gf-Gc model and therefore served as the baseline model for testing the age differentiation-dedifferentiation hypothesis within this theoretical framework. In the extended Gf-Gc model, age differentiation or dedifferentiation is captured by changes in the intercorrelations among broad abilities. Table 3 shows that except for the correlation of Gv with Gc, the correlations between broad abilities increased from age 12 to age 52. To assess the overall effect of dedifferentiation, we computed mean correlations of broad abilities at age 12 and age 52, respectively. Mean correlations were computed by transforming the correlations among abilities into Fisher's z-values, averaging the z-values, and retransforming the average z-value into a correlation coefficient (Cohen, Cohen, West, & Aiken, 2003). This yielded a mean correlation of $\bar{r} = .57$ with a 95% confidence interval of [.48; .67] and $\bar{r} = .75$ with a 95% confidence interval of [.71; .79] at age 12 and age 52, respectively.

---

[2] Effect sizes were computed according to Dunlap, Cortina, Vaslow, and Burke (1996) for mean differences of correlated measures across time.

Table 3
Correlations Among Broad Abilities as Obtained for the Extended Gf-Gc Model

Variable	At age 12				At age 52			
	Gc	Gs	Gv	Gf	Gc	Gs	Gv	Gf
At age 12								
Gc	—							
Gs	.44	—						
Gv	.67	.43	—					
Gf	.59	.49	.74	—				
At age 52								
Gc	.81	.38	.59	.60	—			
Gs	.40	.72	.50	.57	.67	—		
Gv	.50	.22	.87	.71	.68	.56	—	
Gf	.57	.42	.76	.82	.79	.77	.90	—

Note. Gc = comprehension-knowledge; Gf = fluid reasoning; Gv = visual processing; Gs = processing speed. These correlation coefficients are based on the extended Gf-Gc model with metric invariance, partial residual invariance, and partial scalar invariance (Model T1.6). These correlations are identical to those obtained using the extended Gf-Gc model with metric invariance and partial residual invariance.

To study the source of the increased intercorrelations, we examined the age-group-specific variances and covariances of broad abilities. Our results showed that the increased correlations resulted from increased covariances for all broad abilities (see Figure 2a) as well as increased variances for all broad abilities (see Figure 2b), with the largest variance increases for Gc, followed by Gs and Gv. The variance of Gf did not change much across time. These conclusions were corroborated by statistical tests (see Table S4 in the online supplement), in which we imposed equality constraints on covariances (Model CH.1) and variances (Models CH.2 and CH.3) across time and compared the resulting models with the baseline Model T1.6. To conclude, in the extended Gf-Gc model, a significant increase in the mean correlation could be observed from age 12 to age 52, which is indicative of age dedifferentiation. Further, the age dedifferentiation effect was the product of both an increase in covariances and variances of broad abilities.

Carroll's three-stratum model. In the three-stratum model, age dedifferentiation can be caused by (a) increases in the second-order factor loadings of the broad abilities on *g*; (b) decreases in the variances specific to Gf, Gc, Gv, or Gs; and (c) an increase in *g* variance. To study these sources of dedifferentiation, we first needed to test the structural propositions of the model. To this end, we drew on the measurement model T1.6 and introduced a higher order factor representing *g* at age 12 and age 52, respectively. To examine differential stabilities in the framework of the three-stratum theory (described in the next section), we specified correlations between matching specific ability factors and *g* across time, respectively. Preliminary results indicated that the loading of Gf on *g* at age 52 was estimated to be greater than one and thus not admissible. To overcome this problem, we constrained the variance of $Gf_{specific52}$ to zero (Model C.1 in Table S4). This model fit the data well and not considerably worse than Model T1.6 (see Rindskopf & Rose, 1988, who provided the rationale that the higher order factor model is nested within the corresponding first-order factor model).

To identify the various sources of age dedifferentiation, we drew on Model C.1 and imposed several equality constraints across time (see online supplement for a detailed description of these results). In sum, our results showed that the increase in intercorrelations observed in the extended Gf-Gc model is the result of several age-specific changes: (a) increases in the factor loadings of Gc and Gs on *g,* (b) a decrease in the variance specific to Gf with Gf even becoming indistinguishable from *g* at age 52, and (c) by a substantial increase in the variance of *g* over time. However, at the same time, the variance specific to Gc increased, which is indicative of differentiation.

Differential Stabilities

Figure 3 shows the differential stabilities (i.e., the correlations of corresponding factors across age) of the broad abilities in the extended Gf-Gc model as well as the specific abilities and *g* in the three-stratum model. These differential stabilities span 40 years of the participants' lifetimes from late childhood to middle adulthood. Model parameters were taken from Model T1.6 for the extended Gf-Gc model and Model C.3 for the three-stratum model. The values ranged from $r = .72$ to $r = .87$ in the extended Gf-Gc model and from $r = .75$ to $r = .91$ in the three-stratum model. Thus, the results of both intelligence models show very high differential stabilities for all broad abilities, for all specific abilities, and for *g*. This further shows that the differential stabilities of specific abilities, after the influence of *g* has been partialled out, remained high and comparable to the differential stabilities of broad abilities when the influence of *g* had not been controlled for. Finally, no differences between fluid and crystallized abilities were observed for differential stabilities. Hence, both fluid and crystallized abilities as well as *g* were found to be highly stable personal traits from late childhood to late adulthood with only minor shifts in the rank ordering of persons.

Discussion

Cognitive Change in Alternative Structural Conceptualizations of Intelligence

The present study examined two key aspects of the developmental dynamics of cognitive abilities across the lifespan: (a) stability and change in the structure of intelligence with reference to the age differentiation-dedifferentiation hypothesis and (b) differential stabilities from late childhood (age 12) into middle adulthood (age 52). To this end, we took advantage of two alternative structural conceptualizations of intelligence. The extended Cattell-Horn Gf-Gc model (Cattell, 1987; J. L. Horn & Noll, 1997) has dominated previous developmental research and examines broad abilities. Carroll's (1993) three-stratum model is strongly grounded in psychometrically oriented intelligence research and highlights aspects of the data that are not visible when using the extended Gf-Gc model. Specifically, the three-stratum model disentangles developmental processes that are attributable to what is specific to a certain ability (independent of g) from those processes that are shared by all abilities and that are therefore attributable to g.

Age Differentiation-Dedifferentiation

According to the age differentiation-dedifferentiation hypothesis, the structure of intelligence is expected to differentiate

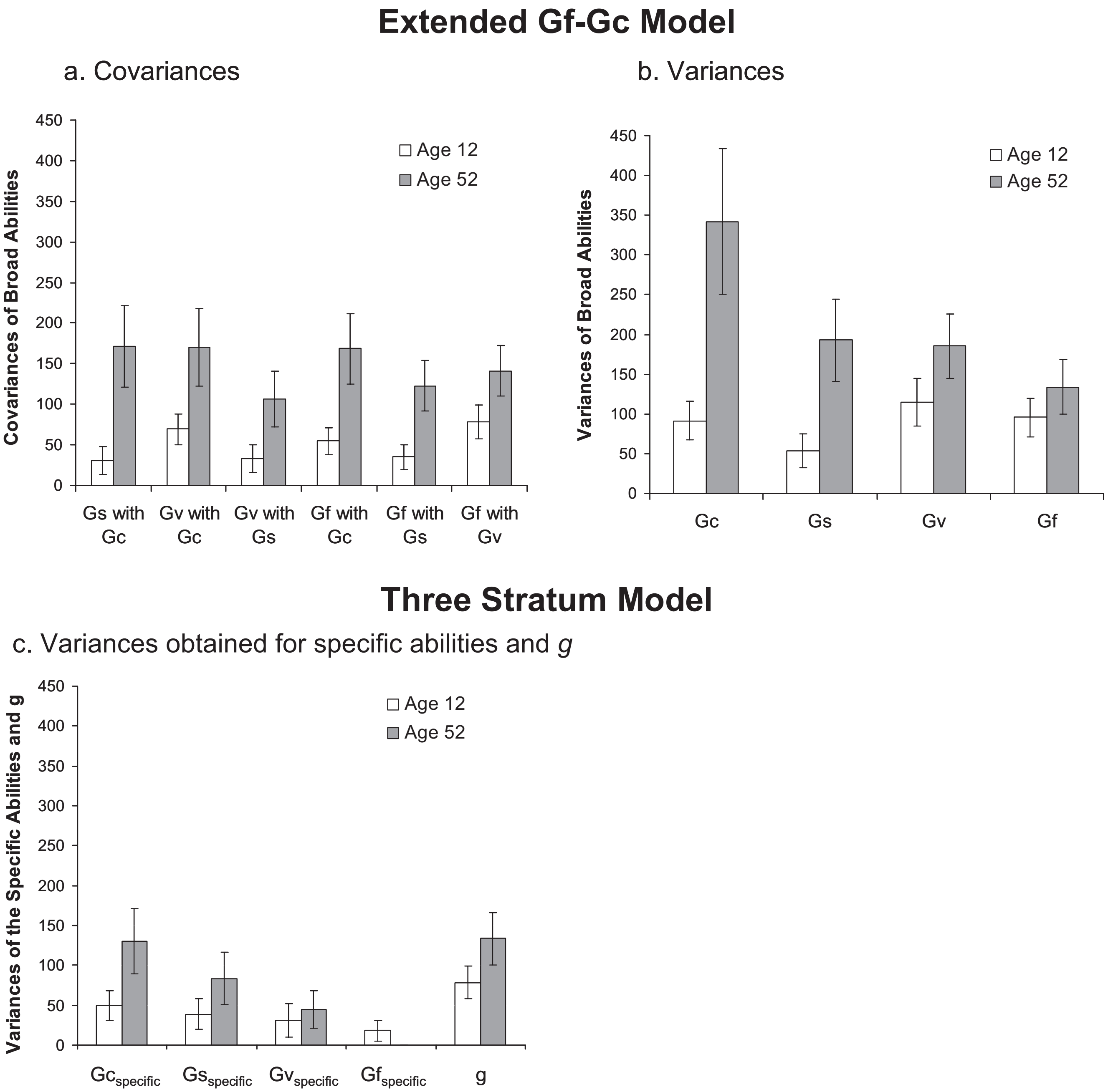

Figure 2. Dedifferentiation of cognitive abilities across time as observed in the extended Gf-Gc model and the three-stratum model. a. Covariances of broad abilities in the extended Gf-Gc model (Model T1.6). b. Variances of the broad abilities in the extended Gf-Gc model (Model T1.6). c. Variances of specific abilities and *g* in the three-stratum model (Model C.3). Error bars represent the 95% confidence intervals. Gf = fluid reasoning; Gc = comprehension-knowledge; Gv = visual processing; Gs = processing speed; *g* = general cognitive ability.

during childhood until late adolescence, keep a fairly stable structure during adulthood, and dedifferentiate in old age. However, irrespective of the structural model applied, the results of the present study seem not to fit well into the theoretically expected pattern, as we found age dedifferentiation from age 12 to age 52. Specifically, in the extended Gf-Gc model, we saw that all covariances between broad abilities increased significantly and substantially from age 12 to age 52. In contrast, the variance increases were substantial for Gc and Gs only, much smaller for Gv and did not reach significance for Gf. However, the increases in the covariances among and the variances of the broad abilities in the extended Gf-Gc model were largely accounted for by variance increases in *g* in the three-stratum model, because the variances of specific abilities (except for

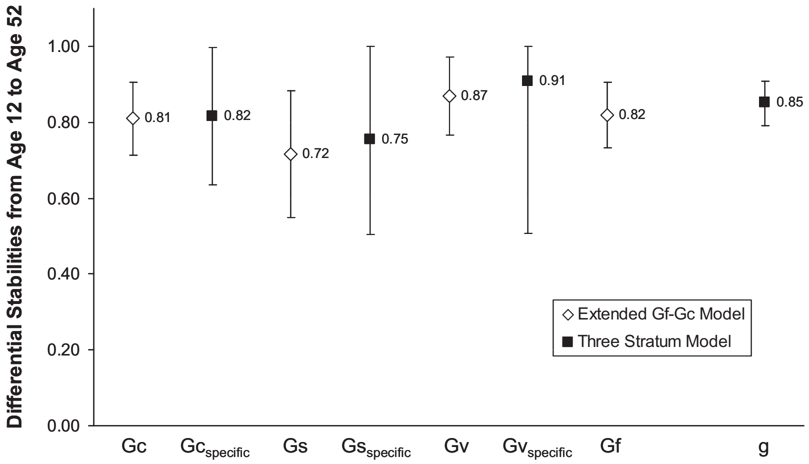

Figure 3. Differential stabilities as correlations of corresponding broad abilities in the extended Gf-Gc model (Model T1.6) and specific abilities as well as *g* in the three-stratum model (Model C.3) from age 12 to age 52. Gf, Gv, Gs, and Gc refer to the broad abilities in the extended Gf-Gc model. Gf$_{specific}$, Gv$_{specific}$, Gs$_{specific}$, and Gc$_{specific}$ refer to specific abilities in the three-stratum model and represent the correlations of the broad ability factors after the influence of *g* has been partialled out. The bars represent the 95% confidence intervals. Gf = fluid reasoning; Gc = comprehension-knowledge; Gv = visual processing; Gs = processing speed; *g* = general cognitive ability.

Gc) did not increase significantly across time. Gc was an exception, demonstrating a large increase in the variance that was specific to Gc even after the influence of *g* was taken into account. This points to the conclusion that changes in the variance of Gc are influenced by a source other than only *g* (to be explained below). Crucially, the two pure markers of fluid (Gf) and crystallized (Gc) abilities exhibited complementary patterns. This was especially visible in the three-stratum model, because the specific variance of Gc increased significantly, whereas the specific variance of Gf decreased to zero and hence became indistinguishable from *g* at age 52.

Differential Stabilities

Our results showed that persons' rank ordering across time concerning (a) their broad abilities in the extended Gf-Gc model and (b) their specific abilities and *g* in Carroll's three-stratum model remained largely stable. This suggests that, across a time span of 40 years, individuals may keep their relative standing with reference to the population in all broad abilities, all specific abilities, and *g*. Thus, in contrast to the study by Larsen et al. (2008), the differential stabilities of specific abilities remained high even though the influence of *g* had been accounted for. In addition, no differences in differential stabilities were indicated for fluid and crystallized abilities or for *g*. Thus, in line with other studies (Conley, 1984; Deary et al., 2000, 2004), our results suggest that the various aspects of intelligence and general intelligence comprise a highly differentially stable construct. Importantly, the results obtained for the three-stratum model also show that when individual differences in *g* are held constant, specific strengths and weaknesses in the cognitive profile (as reflected by the specific abilities) are highly stable. Thus, these results point to the conclusion that it is not only the level of an ability profile (as indicated by g) that remains stable across time but also the pattern of the cognitive profile with regard to an individual's configuration of specific abilities.

Combined Effect of Age Differentiation-Dedifferentiation and Differential Stabilities

In the extended Cattell-Horn Gf-Gc model, we saw that the variances of broad abilities (except Gf) increased, which suggests that people differ more with respect to their broad abilities at age 52 than at age 12. At the same time, all differential stabilities of broad abilities remained high, which shows that individuals keep their relative standing in the population. Hence, initial differences between people on Gc, Gs, and Gv appear to become increasingly larger as life unfolds, and the gap between the two ends of the ability distribution widens across the lifespan. This effect (in combination with the observed increases in latent means and means of the manifest subtest scores shown in Table 2) can be described in the words of Ceci and Paperierno (2005, p. 1) as, "the 'have-nots' gain but the 'haves' gain even more." In the three-stratum model, we saw that (a) the main reason why people differ more greatly at age 52 is captured by an increased *g* variance, although (b) the differential stability of *g* also remains extremely high. Thus, initial differences in *g* become amplified and increasingly important as life unfolds. Moreover, this gap-widening effect of *g* seems to account for large parts of the age dedifferentiation effect, which we observed as increases in the covariances of the broad abilities in the extended Gf-Gc model.

Explanations of Age Dedifferentiation in the Current Study

How can we explain the current finding of age dedifferentiation from age 12 to age 52? Several processes may have acted in combination to produce these results. First, the results of the current study are in line with propositions made by Li and Baltes (2006) that the increasingly heterogeneous environment across the lifespan leads to greater increases in the variance of crystallized than of fluid abilities, because crystallized abilities are more sensitive to the environment. In the extended Gf-Gc model, the variance of Gc increased substantively, whereas the variances of Gv and Gf showed smaller gains. Intuitively, Gs might be expected to be an exception to the proposed pattern, since processing speed is generally considered to be a biologically determined and fluid ability. However, as processing speed mainly involves the ability to concentrate and to focus, it is presumably also affected by environmental opportunities to train these abilities, which can explain the large increase in variance.

Second, according to Ceci and Papierno (2005), gap widening occurs because (a) more gifted people may profit more from environmental opportunities by learning faster (see also Kan et al., 2011), and (b) more gifted people may take better advantage of environmental opportunities (e.g., by seeking environments that are cognitively more challenging and thus more profitable for their cognitive development). This may result in an interaction of the environment with the initial ability level because people actively select or are placed into environments that match their abilities (for similar explanations, see also Dickens & Flynn, 2001; Scarr & McCartney, 1983; Van der Maas et al., 2006).

Third, it seems that the observed process of age dedifferentiation is not explained well by the common cause hypothesis (Baltes & Lindenberger, 1997). According to the common cause hypothesis, decreases in fluid abilities limit the acquisition of crystallized abilities, and as a result, the two kinds of abilities become more similar. This explanation does not fit well with the current results for a number of reasons: (a) Longitudinal studies do not show declines in cognitive abilities until age 50 (Tucker-Drob & Salthouse, 2011). Likewise, we did not observe a decrease in mean levels of fluid abilities from age 12 to age 52 in the current study. On the contrary, the latent means of Gf and Gs point to a substantial increase from age 12 to age 52. (b) The age dedifferentiation in the current study is caused by initial differences between people that become more pronounced. Thus, the current effect originates because the "have-nots" gain but the "haves" gain even more, and a gap widens between the two ends of the distribution. In other words, the effect seems to be caused by unequal gains in cognitive functions between people and not by losses in cognitive functions. Taken together, our results suggest that the common cause hypothesis might be more appropriate for explaining ability dedifferentiation in older age groups.

Fourth, the current pattern of results may be partly explained by several propositions of the investment theory. Specifically, investment theory proposes that fluid abilities are invested into the acquisition of crystallized abilities by taking advantage of environmental learning opportunities. Kvist and Gustafsson (2008) further argued that if this proposition holds true, Gf and *g* should be the same entity because Gf is postulated to be involved in all kinds of learning (see also Kan et al., 2011). This is exactly what we found in the current study: Gf and *g* became indistinguishable at age 52. Further, according to investment theory, age differentiation occurs because the environment becomes increasingly heterogeneous as life unfolds, which affects crystallized abilities to a greater extent than fluid abilities. The described mechanisms are used to explain differentiation of crystallized and fluid abilities. Our results partly supported this prediction, as we found a significant change in $\mathrm{Gc}_{\mathrm{specific}}$ (which is indicative of age differentiation) that may resemble the strong influence of environmental learning opportunities on crystallized abilities. However, the substantial increase in the variance of Gc (in the extended Gf-Gc model) was to a large degree accounted for by variance increases in *g* (in the three stratum model), which implies dedifferentiation of broad abilities with age and not differentiation as proposed by the investment theory.

Strengths and Limitations of the Current Study

In the current study, we examined cognitive development across 40 years of participants' lifespans in a longitudinal sample that was highly homogeneous with respect to age. For this reason, we did not have to arbitrarily divide our sample into two age groups to study the age differentiation-dedifferentiation hypothesis, as has been done in most previous research. Moreover, the longitudinal data base made it possible to analyze both the age differentiation-dedifferentiation hypothesis as well as differential stabilities in the same study. Further, our research design also allowed us to effectively address one major validity threat from which longitudinal designs usually suffer: The time span of 40 years in between the two measurement occasions rendered retest effects almost impossible (Tucker-Drob & Salthouse, 2011).

Despite these strengths, our study was subject to several limitations that should be born in mind when interpreting the present findings and addressed in future research. First, we could not directly tackle one key problem of longitudinal designs—selective attrition (Tucker-Drob & Salthouse, 2011). Notably, the present longitudinal sample reflected important characteristics of the representative base sample of 12-year-old students fairly well, as it was only slightly positively selected in terms of several childhood characteristics including cognitive abilities, parental socioeconomic status, grade point average, gender, and migration background (see Table S2 and Figure S1 in the online supplemental material). Nevertheless, we cannot rule out the possibility that the statistical estimates of individuals' cognitive development may be distorted because of the selective attrition of study participants. For example, deficits related to aging may be underestimated because participants with lower cognitive abilities were more likely to drop out of the current study. This is a typical problem of most longitudinal studies (Tucker-Drob & Salthouse, 2011) and can be a result of several factors, such as an association of lower cognitive abilities with death or illness (Deary, 2010), or disinterest of lower functioning participants due to lower confidence in their own cognitive abilities or in the test.

Second, data were available only for two points of measurement. With only two points of measurement, it is impossible to provide a comprehensive picture of the course of cognitive development (e.g., growth-curve modeling of individuals' cognitive development). Thus, we do not know whether the mean performance of our individuals was already declining after it peaked in late adolescence, as often found in cross-sectional studies, or was not yet in decline, as often estimated by longitudinal studies (Tucker-Drob & Salthouse, 2011). Moreover, we cannot rule out the possibility that the age dedifferentiation effect in the current study was a result of initial differentiation until late adolescence followed by dedifferentiation as proposed by the theory. According to the findings by Tucker-Drob (2009), even the reverse pattern would be possible. Thus, having more measurement occasions at important developmental stages such as in early childhood or late adolescence would have been very valuable to better portray individuals' cognitive development.

Third, Type 1 invariance of measurement properties is needed in order to make meaningful comparisons of latent ability constructs across time. In the present article, we based our conclusions on a measurement model (i.e., T1.6, see online supplement) where subtests demonstrated complete metric invariance of factor loadings, partial invariance of the intercepts, and partial invariance of the residual terms. Particularly, the residual variances of two out of eight subtests were higher at age 52 than at age 12. This may reflect an increase of variance attributable to (a) random measurement error and/or (b) subtest-specific abilities. The latter would indicate another potential source of differentiation of abilities. The available data, however, are insufficient to examine this possibility, as a separate analysis of subtest-specific abilities would require two parallel subtests at each point of measurement, which are not available in the present data set. Clearly, given this level of measurement invariance, changes in mean levels and variances of subtests across time need to be interpreted with great caution, as these changes may reflect changes in target ability constructs (specified as factors in the extended Gf-Gc model or the three-stratum model), as well as changes in subtest-specific abilities or random measurement error. Moreover, it has been debated whether partial invariance of residual terms may complicate the interpretation of factor variances and covariances (DeShon, 2004) or not (T. D. Little, 1997). Here we take the stance that it is reasonable to compare factor variances and covariances (which were central to our research goals) across time even when only metric invariance of factor loadings holds (see, e.g., Widaman & Reise, 1997). Note that estimates of factor variances and covariances may be severely biased when residual terms are specified to be invariant though they are in fact not (as found in the present study). To obtain precise estimates of cognitive development given our data, we therefore followed Little's (T. D. Little, 1997, p. 55, footnote 1) advice and based our conclusion on a measurement model with partial invariance of residual terms, rather than forcing the residual variances to be invariant.

Fourth, we had only two observed indicators as measures of each broad ability factor, which constitutes the lower limit for assessing latent factors in structural equation models. To be able to measure cognitive change, we had to use the same subtests that were given in 1968. Notably, these subtests represent widely used indicators of the broad abilities under investigation. However, when ability factors are measured using only two subtests, the factors may not represent the full conceptual scope of the abilities in question (e.g., the measurement of Gc would have profited from including a curriculum-based test of students' knowledge). Further, subtest scores were not perfectly reliable (see Table S3 in the online supplement), which in turn affects the precision (in terms of standard errors) of statistical parameters reflecting age differentiation-dedifferentiation or differential stabilities. In sum, it is an open question whether the present results on cognitive development are tied to the specific subtests applied or whether the present results may also reflect cognitive change when ability factors are measured using a broader set of subtests. Future research will therefore benefit from administering a broader set of subtests to overcome this limitation and to yield more precise estimates of cognitive development.

Conclusion

The present study examined age differentiation-dedifferentiation and differential stabilities of cognitive abilities in the theoretical framework of (a) the extended Gf-Gc model for studying broad abilities and (b) the three-stratum model for decomposing cognitive change into those processes that are attributable to a certain specific ability (which is independent of *g*) and those that are shared by all broad abilities (which are thus attributable to *g*). The present results suggest that people differ more greatly with respect to broad abilities (except for Gf) as life unfolds and that the rank ordering of persons on all broad abilities remains remarkably stable across time. The combined results of these developmental processes points to considerable gap-widening effects from age 12 to age 52 that can be mainly accounted for by a substantial increase in *g* variance in combination with the high differential stability of *g*. The described gap-widening also led to substantial age dedifferentiation effects. The pattern of results in the current study seems to be well aligned with the predictions of the investment theory, that fluid and crystallized abilities are differentially affected by learning environments and that fluid abilities are invested into the acquisition of crystallized abilities. However, the proposition of the investment theory that these processes lead to age differentiation could only partially be supported, as we found that these processes mainly lead to age dedifferentiation.

References

Ackerman, P. L., & Lohman, D. F. (2003). Education and g. In H. Nyborg (Ed.), *The scientific study of general intelligence: Tribute to Arthur R. Jensen* (pp. 275–292). Oxford, England: Pergamon/Elsevier Science.

Baltes, P. B., Cornelius, S. W., Spiro, A., Nesselroade, J. R., & Willis, S. L. (1980). Integration versus differentiation of fluid/crystallized intelligence in old age. *Developmental Psychology, 16,* 625–635. doi:10.1037/0012-1649.16.6.625

Baltes, P. B., & Lindenberger, U. (1997). Emergence of a powerful connection between sensory and cognitive functions across the adult life span: A new window to the study of cognitive aging? *Psychology and Aging, 12,* 12–21. doi:10.1037/0882-7974.12.1.12

Brunner, M., Nagy, G., & Wilhelm, O. (2012). A tutorial on hierarchically structured constructs. *Journal of Personality, 80,* 796–846. doi:10.1111/j.1467-6494.2011.00749.x

Carroll, J. B. (1993). *Human cognitive abilities: A survey of factor-analytic studies*. New York, NY: Cambridge University Press. doi:10.1017/CBO9780511571312

Cattell, R. B. (1987). *Intelligence: Its structure, growth and action*. Amsterdam, the Netherlands: Elsevier.

Ceci, S. J., & Papierno, P. B. (2005). The rhetoric and reality of gap closing: When the "have-nots" gain but the "haves" gain even more. *American Psychologist, 60,* 149–160. doi:10.1037/0003-066X.60.2.149

Cheung, G. W., & Rensvold, R. B. (2002). Evaluating goodness-of-fit indexes for testing measurement invariance. *Structural Equation Modeling, 9,* 233–255. doi:10.1207/S15328007SEM0902_5

Cohen, J., Cohen, P., West, S. G., & Aiken, L. S. (2003). *Applied multiple regression/correlation analysis for the behavioral sciences* (3rd ed.). Mahwah, NJ: Erlbaum.

Cole, D. A., & Maxwell, S. E. (2003). Testing mediational models with longitudinal data: Questions and tips in the use of structural equation modeling. *Journal of Abnormal Psychology, 112,* 558–577. doi:10.1037/0021-843X.112.4.558

Conley, J. J. (1984). The hierarchy of consistency: A review and model of longitudinal findings on adult individual differences in intelligence, personality and self-opinion. *Personality and Individual Differences, 5,* 11–25. doi:10.1016/0191-8869(84)90133-8

Deary, I. J. (2010). Cognitive epidemiology: Its rise, its current issues, and its challenges. *Personality and Individual Differences, 49,* 337–343. doi:10.1016/j.paid.2009.11.012

Deary, I. J., Egan, V., Gibson, G. J., Austin, E. J., Brand, C. R., & Kellaghan, T. (1996). Intelligence and the differentiation hypothesis. *Intelligence, 23,* 105–132. doi:10.1016/S0160-2896(96)90008-2

Deary, I. J., Whalley, L. J., Lemmon, H., Crawford, J. R., & Starr, J. M. (2000). The stability of individual differences in mental ability from childhood to old age: Follow-up of the 1932 Scottish Mental Survey. *Intelligence, 28,* 49–55. doi:10.1016/S0160-2896(99)00031-8

Deary, I. J., Whiteman, M. C., Starr, J. M., Whalley, L. J., & Fox, H. C. (2004). The impact of childhood intelligence on later life: Following up the Scottish Mental Surveys of 1932 and 1947. *Journal of Personality and Social Psychology, 86,* 130–147. doi:10.1037/0022-3514.86.1.130

DeShon, R. P. (2004). Measures are not invariant across groups without error variance homogeneity. *Psychology Science, 46,* 137–149.

Dickens, W. T., & Flynn, J. R. (2001). Heritability estimates versus large environmental effects: The IQ paradox resolved. *Psychological Review, 108,* 346–369. doi:10.1037/0033-295X.108.2.346

Dunlap, W. P., Cortina, J. M., Vaslow, J. B., & Burke, M. J. (1996). Meta-analysis of experiments with matched groups or repeated measures designs. *Psychological Methods, 1,* 170–177. doi:10.1037/1082-989X.1.2.170

Edwards, J. R., & Bagozzi, R. P. (2000). On the nature and direction of relationships between constructs and measures. *Psychological Methods, 5,* 155–174. doi:10.1037/1082-989X.5.2.155

Eichorn, D. H., Hunt, J. V., & Honzik, M. P. (1981). Experience, personality, and IQ: Adolescence to middle age. In D. H. Eichorn, J. A. Clausen, N. Haan, M. P. Honzik, & P. H. Mussen (Eds.), *Present and past in middle life* (pp. 89–116). New York, NY: Academic Press.

Escorial, S., Juan-Espinosa, M., García, L. F., Rebollo, I., & Colom, R. (2003). Does g variance change in adulthood? Testing the age de-differentiation hypothesis across sex. *Personality and Individual Differences, 34,* 1525–1532. doi:10.1016/S0191-8869(02)00133-2

Ghisletta, P., & De Ribaupierre, A. (2005). A dynamic investigation of cognitive dedifferentiation with control for retest: Evidence from the Swiss Interdisciplinary Longitudinal Study on the Oldest Old. *Psychology and Aging, 20,* 671–682. doi:10.1037/0882-7974.20.4.671

Ghisletta, P., & Lindenberger, U. (2003). Age-based structural dynamics between perceptual speed and knowledge in the Berlin Aging Study: Direct evidence for ability dedifferentiation in old age. *Psychology and Aging, 18,* 696–713. doi:10.1037/0882-7974.18.4.696

Gold, D. P., Andres, D., Etezadi, J., Arbuckle, T. Y., Schwartzman, A. E., & Chaikelson, J. (1995). Structural equation model of intellectual change and continuity and predictors of intelligence in older men. *Psychology and Aging, 10,* 294–303. doi:10.1037/0882-7974.10.2.294

Gottfredson, L. S. (1997). Mainstream science on intelligence: An editorial with 52 signatories, history, and bibliography. *Intelligence, 24,* 13–23. doi:10.1016/S0160-2896(97)90011-8

Gottfredson, L. S., & Deary, I. J. (2004). Intelligence predicts health and longevity, but why? *Current Directions in Psychological Science, 13,* 1–4. doi:10.1111/j.0963-7214.2004.01301001.x

Gottfredson, L. S., & Saklofske, D. H. (2009). Intelligence: Foundations and issues in assessment. *Canadian Psychology, 50,* 183–195. doi:10.1037/a0016641

Hayslip, B., Jr., & Sterns, H. L. (1979). Age differences in relationships between crystallized and fluid intelligences and problem solving. *Journal of Gerontology, 34,* 404–414. doi:10.1093/geronj/34.3.404

Hertzog, C., & Schaie, K. W. (1986). Stability and change in adult intelligence: 1. Analysis of longitudinal covariance structures. *Psychology and Aging, 1,* 159–171. doi:10.1037/0882-7974.1.2.159

Hommel, B., Li, K. Z. H., & Li, S.-C. (2004). Visual search across the life span. *Developmental Psychology, 40,* 545–558. doi:10.1037/0012-1649.40.4.545

Horn, J. L., & McArdle, J. J. (2007). Understanding human intelligence since Spearman. In R. Cudeck & R. C. MacCallum (Eds.), *Factor analysis at 100* (pp. 205–247). Mahwah, NJ: Erlbaum.

Horn, J. L., McArdle, J. J., & Mason, R. (1983). When is invariance not invarient: A practical scientist's look at the ethereal concept of factor invariance. *Southern Psychologist, 1,* 179–188.

Horn, J. L., & Noll, J. (1997). Human cognitive capabilities: Gf-Gc theory. In D. P. Flanagan, J. L. Genshaft, & P. L. Harrison (Eds.), *Contemporary intellectual assessment: Theories, tests, and issues* (pp. 53–91). New York, NY: Guilford Press.

Horn, W. (1962). *Leistungsprüfsystem (L-P-S). Handanweisung* (1st ed.) [Achievement Test Battery (L-P-S): Test manual (1st ed.)]. Göttingen, Germany: Hogrefe.

Horn, W. (1983). *Leistungsprüfsystem (L-P-S). Handanweisung* (2nd ed.) [Achievement Test Battery (L-P-S): Test manual (2nd ed.)]. Göttingen, Germany: Hogrefe.

Kan, K.-J., Kievit, R. A., Dolan, C., & van der Maas, H. L. J. (2011). On the interpretation of the CHC factor Gc. *Intelligence, 39,* 292–302. doi:10.1016/j.intell.2011.05.003

Kangas, J., & Bradway, K. (1971). Intelligence at middle age: A thirty-eight year follow-up. *Developmental Psychology, 5,* 333–337. doi:10.1037/h0031471

Kolan, M. J., & Brennan, R. L. (1995). *Test equating: Methods and practices*. New York, NY: Springer-Verlag.

Kvist, A. V., & Gustafsson, J.-E. (2008). The relation between fluid intelligence and the general factor as a function of cultural background: A test of Cattell's investment theory. *Intelligence, 36,* 422–436. doi:10.1016/j.intell.2007.08.004

Larsen, L., Hartmann, P., & Nyborg, H. (2008). The stability of general intelligence from early childhood to middle-age. *Intelligence, 36,* 29–34. doi:10.1016/j.intell.2007.01.001

Li, S.-C., & Baltes, P. B. (2006). Cognitive developmental research from lifespan perspectives: The challenge of integration. In E. Bialystok & F. I. M. Craik (Eds.), *Lifespan cognition: Mechanisms of change* (pp. 344–363). New York, NY: Oxford University Press. doi:10.1093/acprof:oso/9780195169539.003.0024

Li, S.-C., Lindenberger, U., Hommel, B., Aschersleben, G., Prinz, W., & Baltes, P. B. (2004). Transformations in the couplings among intellectual abilities and constituent cognitive processes across the life span. *Psychological Science, 15,* 155–163. doi:10.1111/j.0956-7976.2004.01503003.x

Lindenberger, U. (2001). Lifespan theories of cognitive development. In N. J. Smelser & P. B. Baltes (Eds.), *International encyclopedia of the social and behavioral sciences* (pp. 8848–8854). Oxford, England: Elsevier. doi:10.1016/B0-08-043076-7/01572-2

Lindenberger, U., & von Oertzen, T. (2006). Variability in cognitive aging: From taxonomy to theory. In E. Bialystok & F. I. M. Craik (Eds.), *Lifespan cognition: Mechanisms of change* (pp. 297–314). New York, NY: Oxford University Press. doi:10.1093/acprof:oso/9780195169539.003.0021

Little, R. J. A., & Rubin, D. B. (2002). *Statistical analysis with missing data* (2nd ed.). New York, NY: Wiley.

Little, T. D. (1997). Mean and covariance structures (MACS) analyses of cross-cultural data: Practical and theoretical issues. *Multivariate Behavioral Research, 32,* 53–76. doi:10.1207/s15327906mbr3201_3

Lubke, G. H., Dolan, C. V., Kelderman, H., & Mellenbergh, G. J. (2003). On the relationship between sources of within-and between-group differences and measurement invariance in the common factor model. *Intelligence, 31,* 543–566. doi:10.1016/S0160-2896(03)00051-5

McArdle, J. J., Ferrer-Caja, E., Hamagami, F., & Woodcock, R. W. (2002). Comparative longitudinal structural analyses of the growth and decline of multiple intellectual abilities over the life span. *Developmental Psychology, 38,* 115–142. doi:10.1037/0012-1649.38.1.115

McGrew, K. (2009). CHC theory and the human cognitive abilities project: Standing on the shoulders of the giants of psychometric intelligence research. *Intelligence, 37,* 1–10. doi:10.1016/j.intell.2008.08.004

Meredith, W., & Horn, J. L. (2001). The role of factorial invariance in modeling growth and change. In L. M. Collins & A. G. Sayer (Eds.), *New methods for the analysis of change* (pp. 203–240). Washington, DC: American Psychological Association. doi:10.1037/10409-007

Millsap, R. E., & Olivera-Aguilar, M. (2012). Investigating measurement invariance using confirmatory factor analysis. In R. Hoyle (Ed.), *Handbook of structural equation modeling* (pp. 380–392). New York, NY: Guilford Press.

Molenaar, D., Dolan, C. V., Wicherts, J. M., & van der Maas, H. L. J. (2010). Modeling differentiation of cognitive abilities within the higher-order factor model using moderated factor analysis. *Intelligence, 38,* 611–624. doi:10.1016/j.intell.2010.09.002

Muthén, L. K., & Muthén, B. O. (1998–2010). *Mplus user's guide* (6th ed.). Los Angeles, CA: Muthén & Muthén.

Neisser, U., Boodoo, G., Bouchard, T. J., Jr., Boykin, A. W., Brody, N., Ceci, S. J., . . . Urbina, S. (1996). Intelligence: Knowns and unknowns. *American Psychologist, 51,* 77–101. doi:10.1037/0003-066X.51.2.77

Nisbet, J. D. (1957). Intelligence and age: Retesting with twenty-four years' interval. *British Journal of Educational Psychology, 27,* 190–198. doi:10.1111/j.2044-8279.1957.tb01410.x

Owens, W. (1966). Age and mental abilities: A second adult follow-up. *Journal of Educational Psychology, 57,* 311–325. doi:10.1037/h0023962

Rindskopf, D., & Rose, T. (1988). Some theory and applications of confirmatory second-order factor analysis. *Multivariate Behavioral Research, 23*(1), 51–67. doi:10.1207/s15327906mbr2301_3

Salthouse, T. A. (1996). The processing-speed theory of adult age differences in cognition. *Psychological Review, 103,* 403–428. doi:10.1037/0033-295X.103.3.403

Scarr, S., & McCartney, K. (1983). How people make their own environments: A theory of genotype→environment effects. *Child Development, 54,* 424–435. doi:10.1111/j.1467-8624.1983.tb03884.x

Schaie, K. W. (2005). *Developmental influences on adult intelligence: The Seattle longitudinal study*. New York, NY: Oxford University Press. doi:10.1093/acprof:oso/9780195156737.001.0001

Schaie, K. W., & Hofer, S. M. (2001). Longitudinal studies in research on aging. In J. E. Birren & K. W. Schaie (Eds.), *Handbook of the psychology of aging* (5th ed., pp. 55–77). San Diego, CA: Academia.

Schaie, K. W., Maitland, S. B., Willis, S. L., & Intrieri, R. C. (1998). Longitudinal invariance of adult psychometric ability factor structures across 7 years. *Psychology and Aging, 13,* 8–20. doi:10.1037/0882-7974.13.1.8

Schaie, K. W., & Strother, C. R. (1968). A cross-sequential study of age changes in cognitive behavior. *Psychological Bulletin, 70,* 671–680. doi:10.1037/h0026811

Schmidt, F. L., & Hunter, J. (2004). General mental ability in the world of work: Occupational attainment and job performance. *Journal of Personality and Social Psychology, 86,* 162–173. doi:10.1037/0022-3514.86.1.162

Schwartzman, A. E., Gold, D., Andres, D., Arbuckle, T. Y., & Chaikelson, J. (1987). Stability of intelligence: A 40-year follow-up. *Canadian Journal of Psychology, 41,* 244–256. doi:10.1037/h0084155

Shea, D. L., Lubinski, D., & Benbow, C. P. (2001). Importance of assessing spatial ability in intellectually talented young adolescents: A 20-year longitudinal study. *Journal of Educational Psychology, 93,* 604–614. doi:10.1037/0022-0663.93.3.604

Strenze, T. (2007). Intelligence and socioeconomic success: A meta-analytic review of longitudinal research. *Intelligence, 35,* 401–426. doi:10.1016/j.intell.2006.09.004

Sturm, W., & Büssing, A. (1982). Ein Vergleich von HAWIE und LPS bei der psychometrischen Einzelfalldiagnostik neurologischer Patienten [A comparison of HAWIE and LPS for psychometric individual case diagnosis of neurological patients]. *Diagnostica, 28,* 348–359.

Sturm, W., Willmes, K., & Horn, W. (1993). *Leistungsprüfsystem für 50-bis 90-Jährige (LPS 50+). Handanweisung* (1st ed.) [Achievement Test Battery for 50 to 90 year olds (LPS 50+): Test manual (1st ed.)]. Göttingen, Germany: Hogrefe.

Tewes, U. (1991). *Hamburg-Wechsler-Intelligenztest für Erwachsene–Revision (HAWIE-R)* [Hamburg Wechsler Intelligence Test for Adults–Revision (HAWIE-R)]. Göttingen, Germany: Hogrefe.

Tucker-Drob, E. M. (2009). Differentiation of cognitive abilities across the life span. *Developmental Psychology, 45,* 1097–1118. doi:10.1037/a0015864

Tucker-Drob, E. M., & Salthouse, T. A. (2008). Adult age trends in the relations among cognitive abilities. *Psychology and Aging, 23,* 453–460. doi:10.1037/0882-7974.23.2.453

Tucker-Drob, E. M., & Salthouse, T. A. (2011). Individual differences in cognitive aging. In T. Chamorro-Premuzic, S. von Stumm, & A. Furnham (Eds.), *The Wiley-Blackwell handbook of individual differences* (pp. 242–267). Oxford, England: Wiley-Blackwell.

Tuddenham, R. D., Blumenkrantz, J., & Wilkin, W. R. (1968). Age changes on AGCT: A longitudinal study of average adults. *Journal of Consulting and Clinical Psychology, 32,* 659–663. doi:10.1037/h0026583

Van der Maas, H. L. J., Dolan, C. V., Grasman, R. P. P. P., Wicherts, J. M., Huizenga, H. M., & Raijmakers, M. E. J. (2006). A dynamical model of general intelligence: The positive manifold of intelligence by mutualism. *Psychological Review, 113,* 842–861. doi:10.1037/0033-295X.113.4.842

Widaman, K. F., & Reise, S. P. (1997). xploring the measurement invariance of psychological instruments: Applications in the substance use domain. In M. Windle & S. G. West (Eds.), *The science of revention: Methodological advances from alcohol and substance abuse research* (pp. 281–324). Washington, DC: American Psychological Association. doi:10.1037/10222-009

Zelinski, E. M., & Lewis, K. L. (2003). Adult age differences in multiple cognitive functions: Differentiation, dedifferentiation, or process-specific change? *Psychology and Aging, 18,* 727–745. doi:10.1037/0882-7974.18.4.727

Received February 4, 2012
Revision received June 27, 2012
Accepted August 7, 2012 ■