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Age-related changes in the mean and covariance structure of fluid and crystallized intelligence in childhood and adolescence☆

Ulrich Schroeders[a,*], Stefan Schipolowski[b], Oliver Wilhelm[c]

[a] *Department of Educational Science, University of Bamberg, Germany*
[b] *Department of Psychology, Humboldt-Universität zu Berlin, Germany*
[c] *Department of Psychology and Education, Ulm University, Ulm, Germany*

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ABSTRACT

Evidence on age-related differentiation in the structure of cognitive abilities in childhood and adolescence is still inconclusive. Previous studies often focused on the interrelations or the *g*-saturation of broad ability constructs, neglecting abilities on lower strata. In contrast, we investigated differentiation in the internal structure of fluid intelligence/*gf* (with verbal, numeric, and figural reasoning) and crystallized intelligence/*gc* (with knowledge in the natural sciences, humanities, and social studies). To better understand the development of reasoning and knowledge during secondary education, we analyzed data from 11,756 students attending Grades 5 to 12. Changes in both the mean structure and the covariance structure were estimated with *locally-weighted structural equation models* that allow handling age as a continuous context variable. To substantiate a potential influence of school tracking (i.e., different learning environments), analyses were additionally conducted separated by school track (academic vs. nonacademic). Mean changes in *gf* and *gc* were approximately linear in the total sample, with a steeper slope for the latter. There was little indication of age-related differentiation for the different reasoning facets and knowledge domains. The results suggest that the relatively homogeneous scholastic learning environment in secondary education prevents the development of more pronounced ability or knowledge profiles.

1. Introduction

The structure and development of cognitive abilities have been a focus of intelligence research for over 100 years (e.g., Cudeck & MacCallum, 2007). Among the different factors discussed in many contemporary theories on the structure of intelligence (Carroll, 1993; Horn & Noll, 1997; McGrew, 2009), fluid intelligence (*gf*) and crystallized intelligence (*gc*) are the most prominent ones. *Gf* reflects individual differences in decontextualized reasoning, that is, the ability to “arrive at understanding relations among stimuli, comprehend implications, and draw inferences”, while *gc* is defined as “acculturation knowledge” measured with “tasks indicating breadth and depth of the knowledge of the dominant culture” (Horn & Noll, 1997, p. 69).

In the present study, we examine age-related changes in the mean and covariance structure of fluid and crystallized intelligence in order to better understand the development of these prominent abilities. Previous studies on differentiation of cognitive abilities frequently used second-order factor models.

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* Corresponding author at: Bamberg Graduate School of Social Sciences, University of Bamberg, 96045 Bamberg, Germany.
E-mail address: ulrich.schroeders@uni-bamberg.de (U. Schroeders).

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Specifically, very broad ability constructs such as *gf*, *gc*, and *gs* (mental speed) are modeled as first-order factors below a second-order *g* factor (e.g., Li et al., 2004; Tucker-Drob, 2009). In such models differentiation is expressed in terms of *g* saturation and the magnitude of first-order factor loadings. However, these studies did not consider structural changes that may occur on lower strata of the ability hierarchy. In the present paper, we address this research desideratum by investigating age-related changes in the factor structure of *gf* and *gc*. We focus our examination to late childhood and adolescence because in these periods of time important decisions with respect to later academic or vocational training are made and the initially homogeneous learning environments begin to diverge. Furthermore, Tucker-Drob and Briley (2014) showed in a comprehensive meta-analysis of longitudinal twin and adoption studies that the stability of cognitive abilities approached asymptote in late childhood. From a behavior genetic perspective this may be due to the fact that sources of interindividual differences in cognition (i.e., genetic, shared environmental, and nonshared environmental) reached high levels of stability by early adulthood. Therefore, the period of time before reaching adulthood seems of particular importance in the present context.

1.1. Age-related changes in the mean structure of gf and gc

Studies on mean changes in *gf* and *gc* were already conducted by Cattell, Horn, and colleagues in the context of the theory of fluid and crystallized intelligence (Cattell, 1971; Horn & Cattell, 1967; Horn & Donaldson, 1980; Horn & Hofer, 1992). Summarizing these results, Horn (2008) emphasized the stability of *gc* with maintenance or improvements through much of adulthood whereas *gf* reaches a peak in late adolescence or early adulthood followed by a steady decline. These results were also supported by findings from developmental psychology over the life span. For instance, Baltes, Staudinger, and Lindenberger (1999) described a two-component model of life span intellectual development similar to the original distinction between *gc* and *gf*. They concluded that the crystallized "cognitive pragmatics" remain relatively stable until old age and start to decline only in very old age. In contrast, the age trajectory of the fluid "cognitive mechanics" is marked by an early rise and decline. The characteristic mean changes with age have been conceptualized as the result of a combination of biological factors (e.g., maturation and aging of the brain) and cultural factors (Baltes, 1997).

Besides the characteristic differences in the mean trajectories between *gf* and *gc*, the changes in reasoning ability or crystallized knowledge presumably also depend on the specific measurement instrument. For instance, for *gc* the assessment may focus on general knowledge typically acquired in school or on more subject-specific knowledge such as vocational knowledge. Because specialized knowledge is mainly acquired outside of school in early adulthood (e.g., vocational training, Ackerman, 2008), the learning curve substantially increases even beyond middle adulthood (Ackerman, 2000; Ackerman & Rolfhus, 1999). Furthermore, there is evidence that the age trajectory of *gc* strongly depends on the content domain captured. Ackerman (2000) reported for a sample of 228 adults aged 21 to 62 on the one hand positive correlations between age and knowledge in the social sciences, humanities, and civics. On the other hand, he found significantly negative correlations between age and the physical sciences. Among the different knowledge domains, the physical sciences had the relatively lowest correlations with a composite of traditional verbal *gc* indicators, but were comparatively highly associated with *gf*. *Gf* itself was substantially negatively correlated with age. These results suggest that the higher the relation of a specific measure to *gf*, for example, a science knowledge test, the more pronounced the age-related decline in that measure. In the case of *gf* measures, the prototypicality of the measure could relate to the magnitude of the decline with age. Reversely, one could assume that the higher the relation of a specific measure to *gc*, the higher the positive age-related gains.

1.2. Age-related changes in the covariance structure of gf and gc

The research reviewed so far focused on the mean structure, that is, on the development of the average ability level in the population. However, possible changes in the covariance structure of cognitive abilities are of particular importance for several reasons: The first reason concerns the invariance of a measurement instrument which holds if the indicators of a measure are invariant with respect to an external variable (e.g., gender or age; Grimm & Widaman, 2012). Measurement invariance is often tested with *multi-group confirmatory factor analysis* (MGCFA; Vandenberg & Lance, 2000). Given that statements concerning the mean structure of latent variables and, thus, the interpretation of mean differences on a construct level are only feasible if strong measurement invariance holds, the inspection of possible changes in the covariance structure is an essential prerequisite for such statements. Second, assumptions about differentiation–dedifferentiation processes are highly relevant for the development of theories on cognitive abilities. For example, in the domain of crystallized abilities Carroll (1993, p. 145) advocated an age-related differentiation of language skills, according to which language skills are limited to understanding oral input and to rudimentary speaking skills in early childhood. But through informal and formal education they are hypothesized to become increasingly more complex and diverse. The question of development is inherently linked to questions of the generalizability of findings to different phases of the life span.

Research on age-related differentiation and dedifferentiation of cognitive abilities (e.g., Baltes, Cornelius, Spiro, Nesselroade, & Willis, 1980; Baltes et al., 1999) dates back to the early observation that in childhood intellectual abilities might be correlated more highly than in adulthood (Garrett, 1946). Accordingly, the factor structure of cognitive abilities might be less differentiated in childhood than it is in adolescence. This assumption is usually studied by investigating a) the number of factors required to account for individual differences in cognitive abilities or b) the factor intercorrelations of a fixed set of presumed cognitive abilities. With maturation the factor structure is hypothesized to differentiate and to be relatively stable in adulthood until old age when dedifferentiation takes place. The lower complexity of the structure of cognitive abilities both at the beginning and at the end of life span may be explained with a stronger influence of neurobiological constraints on intellectual