Measuring fluid intelligence at age four

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A B S T R A C T

Individual differences in the broad ability dimension General fluid intelligence (Gf) are typically assessed with visuospatial problem solving tasks, and particularly so among young children. Such tests may, however, contribute construct-irrelevant variance due to the figural content of the tasks. The main aim of the study is, therefore, to investigate if measures of working memory capacity can add to the measurement of Gf. A sample of 364 children aged four were given a test-battery which included 10 tests designed to measure different aspects of Gf: three visuospatial problem solving tests, two visual short-term memory (STM) tests, two verbal STM tests, and three verbal tests of working memory capacity. Confirmatory factor analysis showed that an oblique model with four factors fitted the data well, as did a bifactor model with a general factor, along with verbal and visual modality factors. The bifactor model was the preferred solution, and it was concluded that the general factor in this model represents Gf. It was also observed that the visuospatial problem solving tests were influenced by both Gf and the visual modality factor, the latter contributing construct-irrelevant variance to the intended measurement of Gf.

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1. Introduction

General fluid intelligence (Gf) is one of the central constructs in the field of intelligence. It was introduced, along with the companion construct General crystallized intelligence (Gc) by Cattell (1963, 1987) to represent two different aspects of General intelligence (g). Gf is interpreted as the capacity to solve novel, complex problems, using operations such as inductive and deductive reasoning, concept formation, and classification. Gc, in contrast, represents individual differences in breadth and depth of knowledge of the language, information and concepts of a culture. While Gf by Cattell (1987) was taken to be largely biologically determined, Gc is acquired through education and experience and it primarily reflects verbal knowledge and skills, as well as declarative knowledge in wide areas.

The Gf-Gc model has been shown to be a useful theoretical framework in many areas of research and it also forms an important part of the Cattell-Horn-Carroll (CHC) consensus model of the structure of cognitive abilities (McGrew, 2005; Schneider & McGrew, 2012). The CHC model includes factors at three strata representing three degrees of generality (Carroll, 1993). Stratum I comprises some 60 narrow factors, while at Stratum II some ten broad factors are identified, among these Gf and Gc. At Stratum III the model includes a single g-factor.

While Gf in the CHC model is only one among a large number of broad factors, this factor carries special interest. Cattell (1987) hypothesized the Gf-factor to be a causal factor influencing individual differences in development of knowledge and skills, and he also hypothesized Gf to be strongly related to g, which hypothesis has obtained support (e.g., Gustafsson, 1984; Valentin Kvist & Gustafsson, 2008). Yet another reason for taking a special interest in Gf is that several studies have shown that there are strong relations between Gf on the one hand and working memory and other executive abilities on the other hand (e.g., Blair, 2006). However, in spite of its great interest from a developmental point of view, the research on Gf among young children is

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relatively limited. The main aim of the present study is to investigate the measurement and conceptualization of fluid intelligence among children at the age of four.

1.1. Conceptions of fluid intelligence

Cattell (1987) defined Gf as a broad cognitive ability that allows flexible adaption of thinking to new problems or situations in which Gc does not provide the answers. Gf appears to be involved whenever a task requires perception of complex relations (Cattell, 1987). These relations can be of many kinds, such as classificatory similarities, causal relations, and inferential relations. Cattell's (1987) Investment theory, which is a dynamic extension of the structural Gf-Gc theory postulates this single, general relation-perceiving ability to be an important early determinant of individuals' development of knowledge and skills (i.e. Gc). In particular, the rate of learning in areas that demand understanding of complex relations, such as reading, arithmetic and abstract reasoning, are assumed to depend on the level of Gf, although motivation, quality of instruction and opportunities to learn are also considered important (Cattell, 1987, p. 139). While the empirical support for Investment theory is mixed (Ackerman & Lohman, 2006), the theory is indirectly supported by the finding that there is a strong or even perfect relationship between Gf and a higher-order g-factor (e.g., Gustafsson, 1984; Gustafsson & Undheim, 1996; Johnson & Bouchard, 2005). This perfect relationship may be explained to be a consequence of the ubiquitous involvement of Gf in acquisition of knowledge, which implies that Gf will be a source of variance in each and every task which requires learning of new knowledge and skills (Ackerman & Cianciolo, 2000; Cattell, 1987; Valentin Kvist & Gustafsson, 2008).

Schneider and McGrew (2012) identified three Stratum I factors of the CHC model as being subsumed under the Stratum II Gf-factor: (1) Induction, or the ability to discover the underlying principles or rules that determine the behavior of a phenomenon; (2) General Sequential Reasoning, or the ability to reason logically using known premises and principles; and (3) Quantitative Reasoning which is the ability to use induction or deduction to reason with numbers, mathematical relations, and operators. However, one main issue in the measurement of Gf is to what extent the content of the tasks influence what is actually measured. Wilhelm (2005) argued that the three Stratum I reasoning factors mentioned above should be understood as content factors, because the tests that indicate these three factors typically rely on figural, verbal and numerical content, respectively. Beauducel, Brocke, and Liepmann (2001) demonstrated, in line with the Berlin Model of Intelligence Structure (see, e.g., Bucik & Neubauer, 1996) that separate figural, verbal and numerical content factors could be identified along with a Gf factor which was involved in all the tests. They concluded that if only one type of content is used to measure Gf, this will cause the measurement to be influenced by construct-irrelevant variance. Beauducel et al. also observed that there has been a shift in the conceptualization of Gf away from being conceived as a domain-general ability to being conceived as a non-verbal or figural ability. This subtle reconceptualization of Gf seems to lie behind the current frequent practice of selecting one or a few visuospatial problem solving tests as markers for Gf.

One difficulty when trying to measure Gf with tasks which represent several content categories with young children is that they typically lack linguistic and mathematical literacy, preventing use of verbal and quantitative content. However, Lakin and Gambrell (2012) analyzed data for grades K-2 from a newly developed version of the Cognitive Abilities Test (Lohman, 2012) in which pictorial item formats were used to represent verbal, quantitative and figural content. They used a bifactor model (e.g., Reise, 2012) to analyze the data, which allowed simultaneous identification of a domain-general Gf factor and the three content domain factors. Lakin and Gambrell (2012) concluded that the picture-based item formats adapted from existing formats are able to measure distinct verbal, quantitative, and figural fluid reasoning abilities in young children, and that proper measurement of Gf requires use of items representing several content domains to avoid construct underrepresentation and construct irrelevant variance.

As far as we are aware there is not yet any test battery which allows such a multi-facetted approach to the measurement of Gf at ages below six, the available tests mainly being figural. However, the expansion of neuro-scientific research has provided a broader basis for understanding Gf and in a review of research, Blair (2006, p. 111) observed that fluid cognitive functions have been described with a variety of terms, such as executive functions, executive attention, effortful control, and working memory capacity. This suggests that a broader conception of Gf may be achieved if visuospatial problem solving tests are combined with measures derived from research on executive functions.

1.2. Executive functions and working memory capacity

Executive functions (EFs) are general-purpose control mechanisms that regulate the dynamics of human cognition and action, being core components of self-control or self-regulation ability (Miyake & Friedman, 2012). Three specific executive functions, in particular, have been focused: (1) inhibition, or the suppression of interfering responses or stimuli; (2) shifting, or the ability to switch between tasks or mental sets; and (3) updating, that is involved in the manipulation of incoming information. Studies of individual differences among adults in the executive functions show both overlap and diversity (Miyake & Friedman, 2012). However, the amount of overlap seems to vary as a function of age. Brydges, Reid, Fox, and Anderson (2012) reviewed six papers that have attempted to replicate the three executive functions, and concluded that they appear to be unitary up to the age of 7 years, while by the age of 10–11 years, the three functions are distinguishable. Brydges et al. (2012) also reported an empirical study of 9 and 12 year old children who were given a test-battery with three tests each of inhibition, shifting and updating. A confirmatory factor analysis (CFA) model with a single general factor of executive functioning fitted the data well in both age groups, thus showing the executive functions to be unitary. This factor had a correlation of .89 with a latent Gf factor defined by two visuospatial problem solving tests, and a correlation of .83 with a latent Gc factor defined by two tests measuring vocabulary and information. These results thus show that that there is a very high relation, albeit not perfect, between a general