That WM correlates positively with gF is not controversial. What is under debate is the mechanism for this correlation. Research suggests that one common link is prefrontal cortex (PFC) functioning (Kane & Engle 2002). For example, human and nonhuman primate studies find significantly reduced WM task performance with PFC lesions that are not observed with more posterior lesions (Kane & Engle 2002). Similarly, patients with PFC lesions demonstrate a marked deficit in gF-loaded task performance compared to healthy controls (Duncan et al. 1995).

To be specific, our view is that differential functioning of the PFC brings about individual differences in executive attention control. According to our view, this general attention ability should reveal itself not only in high-level cognitive tasks such as those designed to measure gF, but also in fairly low-level tasks, provided that the task requires effortful attention control. In one of the most striking examples of this, Kane et al. (2001) (see also Unsworth et al. 2004) found that individuals high in WM capacity ("high spans") performed better than those low in WM capacity ("low spans") in a selective orienting task. Specifically, in the antisaccade condition, subjects had to resist reflexive orienting toward a flashing cue and instead execute a saccade in the *opposite* direction. Low span subjects committed more errors, and, even when their saccade was in the correct direction, they were slower to do so. This result stands in contrast to performance in the prosaccade condition, where both high and low WM span subjects were equally able to orient *toward* the flashing cue.

In another such low-level task, Heitz and Engle (submitted) had subjects perform the Eriksen flanker paradigm. Subjects were to respond with one hand if the center letter was H and with the other hand if the center letter was S. On compatible trials, all the letters were identical (e.g., SSSSS). However, on incompatible trials, the center letter was surrounded by response-incompatible letters (e.g., SSHSS). Thus, to perform this task effectively, subjects had to focus their attention (for example, by constraining their attentional allocation) on the center letter in an effort to filter the surrounding distractor letters. Heitz and Engle (submitted) found that low spans were slower to perform this visual-attention filtering than were high spans. Again, no span differences were evident in the compatible trials, when attentional constraint was unnecessary.

These low-level tasks, though unrelated on their surface to traditional WM-span tasks such as reading span, reliably dissociate low and high WM span participants. This, along with our structural equation modeling studies, suggest that what is important for high-level and low-level cognitive functioning is the ability to control attention, whether this serves the purpose of filtering distractor letters in the visual field or maintaining a list of letters in a distracting environment. Although we do not yet know exactly how this is important for fluid intelligence, the strong relationship between WM and gF, as well as a shared reliance on the PFC, support a view implicating attentional control. Our continued efforts are directed at examining this issue in detail.

Clarifying process versus structure in human intelligence: Stop talking about fluid and crystallized

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Abstract: Blair presumes the validity of the fluid-crystallized model throughout his article. Two comparative evaluations recently demonstrated that this presumption can be challenged. The fluid-crystallized model offers little to the understanding of the structural manifestation of general intelligence and other more specific abilities. It obscures important issues involving the distinction of pervasive learning disabilities (low general intelligence) from specific, content-related disabilities that impede the development of particular skills.

The dominant theoretical model of the structure of human intellect in the psychometric tradition is based on the theory of fluid and crystallized intelligence. Developed initially by Cattell (1943; 1963) and elaborated in greater detail by Horn (1976; 1985; 1998), the theory of fluid and crystallized intelligence distinguishes these two abilities. Fluid ability is demonstrated by solving problems for which prior experience and learned knowledge are of little use. It is measured best by tests having little scholastic or cultural content, such as verbal tasks that rely on relationships among familiar words, or perceptual and figural tasks. Crystallized ability reflects consolidated knowledge gained by education, access to cultural information, and experience. An individual's crystallized ability originates with fluid ability but is developed through access to and selection of learning experiences. Consequently, among people of similar educational and cultural background, individual differences in fluid ability are thought to influence individual differences in crystallized ability. Yet, persons from different cultural backgrounds with the same level of fluid ability are predicted to differ in crystallized ability. This is the theoretical basis for arguing that many intelligence tests are culturally biased.

As conceived initially, fluid-crystallized theory was used to argue against the existence of general intelligence (Cattell 1971; Horn 1989), based on the belief that the higher-order general intelligence factors arising from different batteries of tests would vary. For three widely known test batteries, however, this belief was unfounded (Johnson et al. 2004). In more recent years, Carroll's (1993) monumental and systematic exploratory factor analysis of more than 460 data sets has built some consensus around a three-strata hierarchical model with general intelligence at the highest stratum, and fluid and crystallized abilities prominent among the more specialized abilities in the second stratum. This model effectively synthesizes the ideas of intelligence researchers over the past 100 years.

Blair's creative synthesis makes clear that the descriptive accuracy of this model has been presumed in designing studies spanning the domains of psychology, as well as in designing intelligence assessment tools. It is also assumed by Blair. Surprisingly, received wisdom has not been subject to empirical scrutiny in the form of comparative assessment, despite the existence of other models for the structure of intellect. Two comparative evaluations using modern confirmatory factor-analytic techniques, however, demonstrated clearly that the fluid-crystallized model provides an inaccurate description of the structure of human intellect (Johnson & Bouchard 2005; in press). Vernon's (1964; 1965) more content-based verbal-perceptual model provides greater descriptive accuracy, which is further enhanced by the addition of a factor representing image rotation.

The fluid-crystallized model as extended by Carroll (1993) differs from the Vernon (1964; 1965) model in the definitions of the concepts of fluid and crystallized intelligence and verbal and perceptual abilities. Clarity about these definitions is complicated by the fact that many researchers have tended to conflate fluid intelligence with perceptual abilities, and crystallized intelligence with verbal abilities. The two sets of terms do overlap to a substantial degree, but they can also be distinguished in a straightforward way. As noted, learned knowledge and skill contribute little to manifestations of fluid intelligence but extensively to manifestations of crystallized intelligence. Both Cattell (1971) and Horn (1989) were clear that this distinction in the role of experience applies across content boundaries. In contrast, Vernon's verbal and perceptual abilities follow content areas. Thus, tests involving the explicit use of pre-existing perceptual knowledge would contribute to crystallized intelligence, but not to verbal ability. Further, tests that involve abstract reasoning with factual knowledge would contribute to both fluid and crystallized intelligence, but such tests would not contribute to perceptual ability. The structure of ability follows the verbal-perceptual outline rather than the fluid-crystallized outline (Johnson & Bouchard 2005; in press), rendering the controversy surrounding the question of the equivalence of fluid and general intelligence moot.

Psychometric models of the structure of intellectual ability offer objective and rigorous frameworks for studying genetic (Gottesman 1997; Plomin & Craig, in press) and epigenetically mediated neurobiological endophenotypes and processes (Gottesman & Gould 2003; Weaver et al. 2004), as well as insight into the relative accuracy of the measurement tools we use to assess the ability of individuals and to predict their success in educational and occupational domains. The research Blair describes highlights the limitations of the fluid-crystallized model in addressing these purposes. Paper-and-pencil tests of ability are blunt measurement tools. Performance on any task always reflects learned behavior to at least some degree. People also likely differ in their prior exposure to any task as much as they do in innate ability to address any truly novel task. Consequently, it is never possible to measure innate ability per se, and there is always variance in the degree to which innate ability is reflected in individual test scores. In addition, most problems can be solved using multiple strategies, making it difficult to be sure that any specific task measures any specific ability. Nevertheless, it is clear that the variance common to even a relatively small battery of such tests taps a general intellectual ability with substantial relevance to a wide variety of life outcomes (Gottfredson 1997; Jensen 1998; Lubinski 2004). Blair raises important questions related to the biological development of this general ability in the context of emotional regulation and environmental stress, but we will be able to address these questions more fruitfully by separating the process of development from the structures developed.

Jensen (1998, p. 95) nicely distinguished between processes and structures in their implications for understanding intellectual performance. We may be able to use fluid-crystallized theory to understand how intellectual performance emerges in the individual, but understanding the structural manifestation of general intelligence and other more specific abilities requires comparison across individuals in a systems biology context (Grant 2003). Fluid-crystallized theory has little to offer in this regard. It may even delay the resolution of important issues involving the distinction of pervasive learning disabilities (low general intelligence) from specific, content-related disabilities that impede the development of particular skills. These specific disabilities also tend to follow Vernon's (1965) hierarchical structure of general intelligence supplemented with specific verbal and perceptual abilities, further supplemented with image-rotation ability.

Some considerations concerning neurological development and psychometric assessment

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Abstract: Blair makes a strong case that fluid cognition and psychometric *g* are not identical constructs. However, he fails to mention the development of the prefrontal cortex, which likely makes the Gf–*g* distinction different in children than in adults.[1] He also incorrectly states that current IQ tests do not measure Gf; we discuss several recent instruments that measure Gf quite well.

Blair's target article makes a strong case that fluid cognition and psychometric *g* are not identical constructs. Indeed, these constructs are clearly dissimilar for adults, a notion supported for years by a wealth of aging research generated by Horn and Cattell's (1966) constructs of fluid (Gf)[1] and crystallized (Gc) intelligence. Dramatically different growth curves have been demonstrated for Gf and Gc across the adult life span for numerous adult tests (e.g., Kaufman 2001). Blair includes aging research on the Horn-Cattell constructs as one piece of evidence for the distinctiveness of Gf and *g*, and we agree that this one argument, per se, is stronger than any factor-analytically based psychometric argument that Gf and *g* are virtual identities.

Blair's evidence for the distinctions between Gf and *g* for children, though strongly reasoned and diverse in its breadth, is less compelling than the evidence for adults. Blair appropriately discusses the key role played by the prefrontal cortex (PFC) in fluid cognitive functions, but fails to mention or consider the development of these functions in children. As Golden (1981) indicates, it is not until about ages 11–12, on average, that "the prefrontal areas of the brain that serve as the tertiary level of the output/planning unit develop" (p. 292). This level corresponds to the onset of Piaget's stage of formal operations (Inhelder & Piaget 1958) and the emergence of Luria's (1970) Block 3 planning abilities.

The identification of Gf factors in groups of normal children also has a distinct developmental component. These factors do not emerge as separate constructs until about age 6 or 7 (Elliott 1990; Kaufman & Kaufman 2004). Therefore, the relationship between Gf and *g* in children is likely to be a different phenomenon for children below age 6, for those between 7 and 11, and for adolescents. As multifaceted in scope as Blair's analysis was, his conclusions for children should be treated as tentative pending more thorough developmental analyses.

One other area of Blair's review that was relatively weak was his apparent lack of awareness of the contemporary psychometric scene regarding the assessment of fluid cognition, especially in children. He cited a 15-year-old source (Woodcock 1990) and an 8-year-old source (McGrew 1997) to document "the limited assessment of gF currently available in many widely used intelligence tests" (sect. 4.1, para. 3) and to state that these tests "disproportionately assess crystallized skills and domains of intelligence associated with opportunity for learning" (sect. 7.1, para. 2).

Those claims are simply not true. Tests that deemphasized *g* and provided measurement of fluid cognition began to be published shortly after Woodcock's (1990) article went to press, and have proliferated since McGrew's (1997) chapter was published. The latest versions of the Wechsler and Binet tests are joined by many other well-normed, psychometrically sound, cognitive ability tests that minimize the importance of *g*, emphasize the assessment of multiple abilities and measure fluid cognition. Listed chronologically, the following tests all provide excellent measurement of fluid cognition:

1. *Differential Ability Scales* (DAS [Elliott 1990]), $2\frac{1}{2}$–17 years; includes three scales for school-age children, one of which is a Nonverbal Reasoning Scale that measures Gf (Keith 2005).
2. *Kaufman Adolescent and Adult Intelligence Test* (KAIT [Kaufman & Kaufman 1993]), 11–85+ years; includes two scales named Crystallized Intelligence and Fluid Intelligence; two subtests (Mystery Codes and Logical Steps) are considered excellent measures of Gf (Flanagan & Ortiz 2001).
3. *Wechsler Adult Intelligence Scale*, 3rd edition (WAIS-III [Wechsler 1997]), 16–89 years; added a measure of Gf (Matrix Reasoning) to the Performance Scale, a measure of working memory (Letter–Number Sequencing), and a separate Working Memory Index.
4. *Cognitive Assessment System* (CAS [Naglieri & Das 1997]), 5–17 years; includes four scales derived from Luria's theory, one