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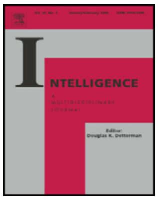

Revisiting the construct of “relational integration” and its role in accounting for general intelligence: The importance of knowledge integration

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Recent research suggests that relational integration is a strong predictor of measures of complex cognitive abilities (e.g., Oberauer, Süβ, Wilhem, & Whittmann, 2008). In this paper we argue that there are at least two types of relational integration and that forming new relational structures by integrating relevant prior knowledge with new information is the fundamental relational integration process that underlies skill at performing many complex cognitive tasks. We describe a simple way to measure individual differences in this knowledge integration process and we show that our knowledge integration measure accounts for an impressive proportion of the variance on a battery of cognitive tests that assessed general fluid intelligence and specific abilities (verbal, quantitative, spatial). Knowledge integration also had better predictive power than two popular measures of the combined storage and processing capacity of working memory (reading span and operation span), as well as another relational integration measure that did not require accessing and integrating prior knowledge.

1. Introduction

Individuals who score well on tests of verbal ability are likely to score well on tests of quantitative ability, spatial ability, abstract reasoning, and so on. The finding that scores on diverse tests of cognitive abilities are invariably positively intercorrelated, albeit to varying degrees, is a robust psychometric phenomenon that generalizes across different batteries of cognitive tests and a variety of populations (Carroll, 1993; Eysenck, 1939; Jenson, 1998; Johnson, Bouchard, Krueger, McGue, & Gottesman, 2004; Van der Maas et al., 2006). Spearman (1904, 1927) attributed the shared variance among cognitive tasks to a single underlying factor that he labeled “g” and he believed that “g” provided the key to understanding intelligence. Spearman also invoked the construct of “mental energy” to explain the nature of individual differences in *g*. Because *g* has been an excellent predictor of important real-world outcomes such as academic and job success (Deary, 2001a; Gottfredson, 1997; Higgins, Peterson, Pihl, & Lee, 2007; Schmidt & Hunter, 1998), contemporary cognitive researchers have continued in Spearman's quest to understand the nature of g, and they have invoked explanatory constructs such as information-processing speed (Jenson, 1987), inspection time (Deary, 2000, 2001b), working memory capacity and functions (Engle, Tuholski, Laughlin, & Conway, 1999; Kyllonen & Christal, 1990; Oberauer, Sűß, Wilhelm, & Wittman, 2008) with varying success (for reviews, see Deary, 2001b, 2002; Detterman, 2002; Jenson, 1998).[1] In this article, we propose yet

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[1] There have also been attempts to understand general intelligence in terms of biological factors such as brain size, neural efficiency, and neural plasticity (Detterman, 2002; Garlick, 2002; Gray & Thompson, 2004), but this is not the focus here.

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another cognitive candidate—the ability to integrate prior knowledge with new information. We argue that a common denominator among many cognitive ability tasks is the requirement that problem solvers are able to access relevant knowledge from long-term memory and integrate this knowledge with the new problem information in order to build new relations (see Oberauer et al., 2008, for a related albeit not identical argument). We describe a way to measure *knowledge integration* and show that this measure is strongly associated with measures of specific cognitive abilities (verbal, quantitative, spatial), measures of fluid intelligence (e.g., Ravens Matrices, Cattell's Culture Fair Test), and a composite measure of "g" that we call general intelligence.

1.1. Previous approaches to understanding the cognitive bases of general intelligence

With the rise of cognitive or information-processing psychology in the 1970s came the optimism that individual differences in performance on complex cognitive tasks could be reduced to, or understood in terms of, individual differences in elementary or micro-level cognitive processes (Sternberg, 1978). A popular candidate for this cognitive reductionistic approach has been *speed of information processing* (Deary, Der, & Ford, 2001; Jenson, 1987; Neubauer, 1997; see Deary, 2001b, for a review). Early on researchers observed a small but significant correlation between reaction-time and performance on psychometric measures of intelligence (see Beck, 1933 for an example), but what was most appealing about the information-processing approach was that it gave birth to a number of reaction-time tasks and manipulations that allowed for the fractionation of overall reaction times into separate parameters or "mental elements" (Deary, 2001b, p. 167). For example, Hick's (1952) reaction-time task, which systematically increased the number of stimulus choices in a choice reaction-time situation, broke reaction time into decision time, movement time, and slope (reaction times plotted against number of stimulus alternatives), which was assumed to provide an estimate of an individual's 'rate of gain of information.' Unfortunately the problem was that decision times and movement times for Hick's reaction-time tasks showed only small significant correlations of around .20 with complex cognitive ability test scores (faster times are associated with higher test scores); see Jenson (1987, 1998) for examples. Moreover, the theoretically interesting slope parameter for Hick's reaction-time task did no better, and was often more weakly correlated with the cognitive ability tests.

Studies using Saul Sternberg's (1966) memory scanning task and Posner and Mitchell's (1967) letter-matching task have produced similarly disappointing results (Deary, 2000; Neubauer, 1997). The slope of the Sternberg memory scanning task is assumed to capture the time it takes an individual to scan a single item in short-term memory; for the Posner and Mitchell letter-matching task the difference in reaction time to respond 'same' when two letters share the same name (e.g., A a) relative to when they share the same physical identity (e.g., A A) is assumed to capture the time it takes an individual to access lexical or semantic information from long-term memory. Again, the typical finding has been that overall reaction times in both of these tasks correlate with scores on complex cognitive tasks, but the theoretically interesting slope and difference parameters show no special correlations. These findings have left some researchers questioning how productive the research on reaction time and intelligence can be. As Deary (2001b) puts it, "Once it is realized that all manner of reaction-time parameters correlate significantly with mental test scores it has to be asked how much we have really understood about intelligence" (p. 166).

A low-level visual information-processing task called *inspection time* (Nettelbeck, 1987; Nettelbeck & Lally, 1976; Vickers, Nettelbeck, & Wilson, 1972; see also Crawford, Deary, Allan, & Gustaffson, 1998; Deary & Stough, 1996) has produced somewhat stronger correlations with scores on cognitive ability tests than have the reaction-time tasks just described. In a typical version of the inspection time task, a stimulus consisting of two vertical lines of unequal lengths (e.g., 25 mm and 35 mm) is presented on a computer screen for a duration that can vary from a few milliseconds to a few hundred milliseconds. A mask replaces the stimulus immediately after stimulus offset and participants must indicate, at their own pace, which of the lines is longer. Stimulus duration is manipulated by the experimenter to obtain an estimate of the minimum exposure time required for the participant to respond with at least 90% accuracy. The research has shown that correlations between inspection time and cognitive test scores are at around .40 or higher (for meta-analyses, see Grudnick & Kranzler, 2001; Kranzler & Jensen, 1989), with the correlations being stronger for non-verbal (performance) tasks than for verbal ones (Crawford et al., 1998). Nevertheless, despite the success of linking a lower-level aspect of information processing to general intelligence, there is still the belief that "the nature of inspection time and the mechanisms of the association between inspection time and intelligence are far from fully understood" (Deary, 2001b, p. 167).

In contradistinction to the cognitive reductionistic approach, some researchers have attempted to understand individual differences in performance on complex cognitive tasks in terms of higher-level cognitive constructs such as working memory capacity and general control processes (Daneman & Carpenter, 1980; Embretson, 1995; Engle et al., 1999; Kane, Hambrick, & Conway, 2005; Kyllonen & Christal, 1990; Oberauer, Schulz, Wilhelm, & Sűß, 2005). Daneman and Carpenter (1980) developed a measure of the concurrent storage and processing capacity of working memory (called the reading span), and they showed that this measure is highly correlated with tests of reading comprehension and verbal ability, whereas traditional storage-only tests (such as digit span and word span) are at best weakly correlated with verbal ability (see Daneman & Merikle, 1996, for a meta-analysis). Engle et al. (1999) showed that measures of working memory capacity that require concurrent storage and processing, such as the reading span and operation span, are excellent predictors of tests of reasoning ability or general fluid intelligence (*gF*), whereas the simple storage measures are not. Indeed, because the correlation between working memory capacity and reasoning ability or general intelligence is often so high, some researchers have asserted that working memory capacity and general intelligence may be essentially the same construct (e.g., Colom, Rebollo, Palacios, Juan-Espinosa, & Kyllonen, 2004; Engle, 2002; Jenson, 1998; Kyllonen, 2002). Of course, the tests used to measure working memory capacity are themselves very complex (Daneman & Hannon, 2007; Detterman, 2002;