Intelligence 47 (2014) 122–133

Contents lists available at ScienceDirect

Intelligence

Fluid intelligence shares closer to 60% of its variance with working memory capacity and is a better indicator of general intelligence

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ARTICLE INFO

Article history:
Received 30 May 2014
Received in revised form 18 August 2014
Accepted 15 September 2014
Available online 6 October 2014

Keywords:
Working memory
Fluid intelligence
General intelligence

ABSTRACT

A number of empirical studies have examined the association between working memory capacity (WMC) and fluid intelligence (g_f), with conclusions varying from constructs that are substantially distinct to constructs that are isomorphic. A review of the empirical literature suggests that these disparate conclusions are likely due to a number of factors, including the use of tests of varying quality, tests which share method variance, small sample sizes, and samples of varying representativeness of the population. Consequently, in this investigation, the association between WMC and g_f was estimated based on well validated adult Wechsler scale subtests and a large, normative sample ($N = 2200$). Based on a correlated two-factor model, the correlation between WMC and g_f was estimated at $r = .77$ (95% CI: .74/.80), suggesting a substantial level of shared variance, but a meaningful level of uniqueness, as well. Furthermore, based on a bifactor model and omega specific (ω_s), both WMC and g_f were found to be associated with approximately equal standardized levels of unique common variance: WMC $\omega_s = .18$ (95% CI: .12/.23) and g_f $\omega_s = .19$ (95% CI: .13/.25). Finally, further evidence of divergent validity was obtained, as the g_f subtests were observed to be more substantial indicators of general intelligence (g) than the WMC subtests. It is concluded that WMC and g_f share approximately 60% of their true score variance, rather than the commonly cited 50%. Additionally, g_f should be considered a better indicator of g than WMC on both empirical and theoretical grounds.

The association between working memory capacity (WMC) and fluid intelligence (g_f) has been the subject of a substantial amount of empirical work, with a considerable amount of variability in the results, from suggestions that the two constructs are only moderately related (e.g., Ackerman, Beier, & Boyle, 2005; Chuderski, 2013) to constructs that are isomorphic or nearly so (e.g., Blair, 2006; Colom, Rebollo, Palacios, Juan-Espinosa, & Kyllonen, 2004; Kane & Engle, 2002; Kyllonen & Christal, 1990). Much of the empirical research in the area has been suggested to be limited due to small sample sizes, poor sample representativeness, psychometric measures of varying quality, shared method variance, and, finally, questionable data analytic practices (Chuderski, 2013; Gignac, 2007; Oberauer, Schulze, Wilhelm, & Süß, 2005; Yuan, Steedle, Shavelson, Alonzo, & Oppezzo, 2006). Consequently, the purpose of this investigation was to estimate the association between WMC and g_f based on a large ($N = 2200$) normative sample, psychometric measures of at least very good quality, and, arguably, appropriate data analytic techniques. In the event that WMC and g_f were observed to be dissociable statistically within a correlated two-factor model, it was considered additionally useful to investigate the possibility that WMC and g_f may be associated differentially to general intelligence (g), as this would be further evidence in favour of divergent validity associated with the two constructs.

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http://dx.doi.org/10.1016/j.intell.2014.09.004
0160-2896/

1. Some historical and theoretical considerations

WMC has been defined as the ability to maintain and manipulate information temporarily during cognitive activity (Baddeley, 2002; Baddeley & Hitch, 1974). Although investigated primarily from an experimental perspective early on, more recently, WMC has been examined within the context of an important individual differences construct (Conway, Jarrold, Kane, Miyake, & Towse, 2007). In fact, WMC has been suggested to be the fundamental basis of intelligence (e.g., Colom et al., 2004). By contrast, historically, within the area intellectual assessment, individual differences in memory capacity were considered one of the least important indicators of intelligence. Notably, with respect to the Wechsler Adult Intelligence Scale (WAIS; Wechsler, 1955), there was a desire to remove the lone memory subtest from the battery, Digit Span, as it was considered “a poor measure of intelligence” (Matarazzo, 1972, p. 204).

Digit Span is comprised of two forms: forward and backward. In Digit Span Forward, a list of numbers is read to the participant who is then required to repeat the numbers in the order they were read. By contrast, in Digit Span Backward, a list of numbers is read to the participant who is then required to repeat the numbers in the reverse order they were read. Although there was some acknowledgment that Digit Span Backward was more difficult to complete, as it required greater attention, concentration, and effort (Matarazzo, 1972), historically, little consideration was paid to the distinction between Digit Span Forward and Digit Span Backward. In fact, the forward and backward scores were long recommended to be combined into a single composite score (Matarazzo, 1972; Wechsler, 1955, 1981, 1997), even within the comprehensive Wechsler Memory Scales (Wechsler, 1987, 1997). However, some researchers nonetheless began to analyze forward and backward span data separately. For example, O'Donnell, Squires, Martz, Chen, and Phay (1987) found that evoked potential latencies correlated statistically significantly with Digit Span Backward, but not with Digit Span Forward, in a sample of individuals diagnosed with Parkinson's disease. O'Donnell et al. postulated that the differential results may have been because Digit Span Backward requires greater mental manipulation. Digit Span Backward is now more widely recognized as a measure of working memory (Hebben & Milberg, 2009; Wilde & Strauss, 2002), as it incorporates a core element of the construct: the ability to store and manipulate information simultaneously (Oberauer, Süß, Schulze, Wilhelm, & Wittmann, 2000). Within the context of Badeley's model (Baddeley, 2002; Baddeley & Hitch, 1974), forward span is considered to be managed largely by the slave systems (phonological loop and visual-spatial sketchpad) and backward span, which requires additional mental processing, is theorized to rely to a much greater degree upon the central executive (Baddeley, 1996). In the latest edition of the WAIS (WAIS-IV; Wechsler, 2008a), the interpretative manual provides separate Digit Span Forward and Digit Span Backward percentile scores (as well as combined percentiles; Wechsler, 2008b).

In a further recognition of the importance of the working memory construct, two additional working memory subtests have been added to the WAIS. Specifically, the WAIS-III introduced the Letter–Number Sequencing subtest (Wechsler, 1997), which requires participants to recite, in alphabetical and numerical order (smallest to largest), a series of intermingled letters and numbers presented orally. Additionally, the WAIS-IV introduced Digit Span Sequencing, which requires participants to recite, in numerical order (smallest to largest), a series of numbers presented orally (Wechsler, 2008a). Thus, including Digit Span Backwards, the WAIS-IV has three indicators of working memory.[1]

Despite the fact that the current version of the WAIS has three indicators of working memory, very little (if any), latent variable modeling research has included all three of these subtests in their models. For example, the published confirmatory factor analytic (CFA) work continues to use the combined Digit Span composite scores and, furthermore, does not include the Digit Span Substitution subtest scores in any of the models (e.g., Benson, Hulac, & Kranzler, 2010; Gignac & Watkins, 2013; Ward, Bergman, & Hebert, 2011). Consequently, it was considered potentially advantageous to model a working memory latent variable based on the Digit Span Backward, Digit Span Sequencing, and Letter–Number Sequencing subtest scores to test hypotheses relevant to working memory.

In contrast to individual differences in memory capacity, individual differences in reasoning ability have long been regarded as a fundamental element of general intellectual functioning (Lohman & Lakin, 2011). Reasoning may be defined as the cognitive process of formulating a judgment based on the analysis of information (Burt, 1922). Spearman (1923) postulated that the construct most elemental to *g* was similar to reasoning; specifically, the ‘eduction of relations and correlates,’ which represents the capacity to identify the conceptual connectedness between two or more stimuli (Spearman, 1927). Cattell (1943) later bifurcated *g* into two correlated factors: crystallized intelligence (g_c) and fluid intelligence (g_f). Although these factors were later joined by additional second-stratum factors, including Visual Spatial Thinking (g_v), Long-Term Retrieval (g_{lr}), and Processing Speed (g_s) (Carroll, 2003; Horn & Cattell, 1966), both g_f and g_c have been acknowledged to be the strongest second-stratum factors within the cognitive ability domain (Cattell, 1987; although see Johnson & Bouchard, 2005, for a different view). At the highest level of abstraction, Cattell (1963) defined g_f as the ability to adapt to new situations. Operationally, Cattell (1943) defined g_f as the capacity to perceive novel, abstract relations that do not depend on any particular content. Well-regarded psychometric tests of g_f include the Culture Fair Intelligence Test (CFIT; Cattell & Cattell, 1961) and Raven's Advanced Progressive Matrices (RAPM; Raven, Court, & Raven, 1983).

Despite the fact that tests such as the CFIT and RAPM test have long been regarded as excellent measures of intelligence, and g_f in particular (Jensen & Weng, 1994; Kline, 2000; Raven, 2000), neither the WAIS nor the WAIS-R included a relatively pure measure of g_f, although many consider Block Design as a

[1] According to Wechsler (1997, 2008b), the Arithmetic subtest is specified to be associated with the working memory index. However, several empirical investigations have failed to observe Arithmetic to be a meaningful indicator of working memory (Watkins & Ravert, 2013). For example, based on a bifactor model of the WAIS-IV, Gignac and Watkins (2013) found Arithmetic to be associated with a non-significant loading of .08 on the nested working memory factor. A very similar effect was observed for the WAIS-III (Gignac, 2006b). Consequently, for the purposes of this investigation, Arithmetic was considered primarily an indicator of quantitative reasoning.