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There may be nothing special about the association between working memory capacity and fluid intelligence

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ABSTRACT

The association between working memory capacity (WMC) and fluid intelligence (g_f) has been described as substantial and important. In a recent investigation, Gignac (2014a) contended that WMC and g_f share closer to 60% of their variance, rather than the commonly cited 50%, based on an analysis of the Wechsler Adult Intelligence Scale—IV (Wechsler, 2008) normative sample ($N = 2200$). However, Gignac's (2014a) investigation was limited in that it included only completely homogeneous g_f (spatial) and WMC (verbal) subtests, as well as only adults in the sample. Consequently, the purpose of this investigation was to replicate and extend Gignac (2014a) by estimating the association between WMC and g_f, based on the Wechsler Intelligence Scale for Children—Fifth Edition (Wechsler, 2014) normative sample ($N = 2200$), which includes a mix of verbal and spatial WMC subtests. Based on a correlated two-factor model, the correlation between WMC and g_f was estimated at .77 ($r^2 = .59$) which is a perfect replication of Gignac (2014a). However, based on a higher-order model which included all 18 of the WISC-V's subtests, the association between WMC and g_f was found to be non-significant ($-.10$, $p = .152$) after controlling for the effects of general intelligence. Consequently, the commonly suggested notion that WMC and g_f share unique cognitive and or neural processes was not considered supported, based on the results of this investigation.

1. Introduction

The nature and magnitude of the association between working memory capacity (WMC) and fluid intelligence (g_f) has been the subject of a substantial amount of empirical and theoretical research (Conway & Kovacks, 2013). The nature of the association between WMC and g_f has been described as fundamental, as WMC is considered a rate limiting factor in the performance of g_f problems (Carpenter, Just, & Shell, 1990; Fry & Hale, 1996; Oberauer, Su, Wilhelm, & Sander, 2007). From an empirical perspective, it is commonly stated that approximately 50% of the true score variance between WMC and g_f is shared, as Kane, Hambrick, and Conway (2005) reported a meta-analytically derived latent variable correlation of .72 ($r^2 = .52$), based on 14 samples (total $N = 3168$).

In a recent investigation, Gignac (2014a) suggested that the commonly cited 50% shared variance reported by Kane et al. may be smaller than what would be expected at the adult population level, as the vast majority of the samples included in the Kane et al. meta-analysis were based on university students (i.e., range restricted samples). Consequently, Gignac (2014a) tested a correlated two-factor model based on the WAIS-IV (Wechsler, 2008) normative sample data ($N = 2200$) and obtained a correlation of .77 ($r^2 = .59$) between WMC (Digit Span Backward, Digit Span Sequencing, and Letter–Number Sequencing) and g_f (Matrix Reasoning, Figure Weights, and Block Design), which suggested that they share closer to 60% of their true score variance.

Although a correlation of .77 may be considered substantial, Gignac (2014a) hinted at the possibility that the association between WMC and g_f may not be particularly special, by pointing out that the latent variable association between WMC and crystallised intelligence (g_c) was also very large ($r = .66$). Arguably, a more rigorous method that could be used to evaluate the question of special or unique association between WMC and g_f would be to use a higher-order model. Specifically, one would expect to observe a correlation between the residuals associated with the WMC and g_f first-order factors within a comprehensive higher-order model of intelligence, if there were cognitive and/or neural processes unique to WMC and g_f that caused them to correlate with each other. By contrast, the absence of a correlated first-order factor residual between WMC and g_f within a well-fitting higher-order model would imply that the association between WMC and g_f is mediated completely by g (see Gignac, 2008, for a discussion on the higher-order model and mediation). In such a case, the association between WMC and g_f would not be considered special or unique.

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Instead, WMC and g_f would simply be considered two indicators of g, much like g_c and processing speed (g_s), only perhaps stronger.

Based on a higher-order model, Gignac (2014a) did in fact report that WMC (.84) and g_f (.94) were superior indicators of g in comparison to g_c and g_s. Furthermore, Gignac (2014a) found g_f to be superior to WMC as an indicator of g ($p < .001$). Although not discussed by Gignac (2014a), it is worth noting that the results associated with his well-fitting higher-order model of the WAIS-IV did not include a correlation term between the WMC and g_f first-order factor residuals, which suggests the absence of a special or unique association between these two constructs. Additionally, the product of the WMC and g_f second-order factor loadings ($.84 * .94 = .79$) corresponded nearly exactly to the WMC and g_f correlated two-factor model correlation ($r = .77$), which suggests that the WMC and g_f association was mediated completely by g.

A distinct limitation associated with the Gignac (2014a) investigation, however, was that all of the g_f subtests were spatial in nature, while all of the WMC subtests were verbal in nature. Such inter-construct subtest homogeneity may have, to some degree, caused the WMC and g_f inter-association to be smaller than it would otherwise be. Gignac (2014a) suggested that a more convincing approach to the estimation of the WMC and g_f association would be to include at least some mix of spatial and verbal subtests across the two constructs. Fortuitously, the recently released WISC-V (Wechsler, 2014a) includes a spatial working memory subtest, Picture Span. Consequently, the opportunity to model a WMC and g_f correlated two-factor model, as well as a comprehensive higher-order model with a somewhat content heterogeneous WMC latent variable is now possible with a large normative sample ($N = 2200$).

Gignac's (2014a) investigation was also limited in that the sample consisted solely of adult participants (ages: 16 to 90 years). Consequently, Gignac (2014a) could only assume that the WMC and g_f .77 correlation extended to children. Based on the differentiation and de-differentiation hypotheses (see Tucker-Drob, 2009, for example), it is possible that the association between WMC and g_f may decrease or increase in magnitude across human development. Alternatively, it is also possible that the approximate 60% shared variance between WMC and g_f remains relatively constant throughout life, from childhood to old age, consistent with the indifferentiation hypothesis (Juan-Espinoza, Cuevas, Escorial, & Garcia, 2006). Based on a large number of normative Wechsler battery samples (not including the WISC-V), Gignac (2014b) found that that the strength of the g factor remains relatively constant from ages 2.5 to 90 years. In light of the above, the attempt to replicate the results of Gignac (2014a) in a sample of children aged 6 to 16 years of age was considered useful.

In summary, the purpose of this brief investigation was to replicate the results of Gignac (2014a) with a cognitive ability test battery that included a mix of verbal and spatial working memory subtests, as well as a large normative sample of children. Additionally, it was considered beneficial to evaluate specifically the possibility that the WMC and g_f association may not be special or unique, as determined within a higher-order modeling framework.

2. Method

2.1. Sample

The analyses were performed upon the complete normative sample ($N = 2200$) inter-subtest correlation matrix associated with the WISC-V (Wechsler, 2014b). The WISC-V normative sample was obtained based on a stratified sampling strategy to reflect the US census results relevant to gender, age, race/ethnicity, education, and geographic location (Wechsler, 2014b). The WISC-V normative sample age range is 6 to 16 years. In addition to the total sample, the analyses were performed across the following age groups: 6–7 years ($N = 400$), 8 to 9 years ($N = 400$), 10 to 11 years ($N = 400$), 12 to 13 years ($N = 400$), and 14 to 16 years ($N = 600$).

2.2. Materials

The WISC-V consists of a total of 18 core and supplemental subtests (Wechsler, 2014a). Matrix Reasoning (MR) and Figure Weights (FW) may be considered excellent indicators of g_f, as they consist of novel problems that require the identification of patterns in stimuli to be solved (Wechsler, 2014a). In addition to MR and FW, the Block Design (BD) subtest is often considered an indicator of g_f (Goldstein, 2008), although perhaps not as pure a measure of g_f as MR and FW. The WISC-V (Wechsler, 2014b) technical manual specifies a Perceptual Reasoning first-order factor defined by MR, Picture Concepts (PC), FW, and AR. However, based on a bifactor model of the WISC-V normative sample, Canivez and Watkins (in press) found that PC had a very negligible loading (.06) on the nested Perceptual Reasoning latent variable. Therefore, PC was not considered a good indicator of g_f in this investigation. Visual Puzzles (VP) may be argued to be a good indicator of g_f, however, to-date, very little research has been conducted with the VP subtest within the Wechsler scales. Because Gignac (2014b) did not use VP as an indicator of g_f, we opted to use MR, FW, and BD as indicators of g_f for the purposes of consistency. However, for the purposes of robustness analyses, some re-testing was performed with VP as an indicator of g_f.

We did not consider Arithmetic a measure of g_f, as it requires the application of previously learned operations to solve the items successfully. Furthermore, based on a bifactor model of the WISC-V ($N = 2200$), we found that Arithmetic loaded negatively ($-.10$) onto a nested Perceptual Reasoning factor (full results available upon request). Canivez and Watkins (in press) found Arithmetic to be, at best, a very negligible loader (.13) onto a nested WM factor (see also Gignac & Watkins, 2013). Consequently, in light of the above, we considered Arithmetic to be only an indicator of g within the context of the WISC-V.

Digit Span Backwards (DSB), Digit Span Sequencing (DSS), and Letter–Number Sequencing (LN) may be considered very good to excellent measures of WMC (Sattler & Ryan, 2009). Finally, Picture Span (PS) is described by Wechsler (2014a) as a working memory subtest, as it requires the participant to identify on a response sheet the stimuli that were presented on a stimulus page in the order with which they were presented. Canivez and Watkins (in press) found PS to be an appreciable loader (.30) on a nested working memory factor, based on the WISC-V normative sample.

Verbal Comprehension subtests within the WISC-V include Vocabulary (VOC), Information (IN), Comprehension (CO) and Similarities (SI). In our view, Similarities contains too much abstraction skill to be considered a relatively pure measure of g_c, although it does appear to share a non-negligible amount of variance with a nested Verbal Comprehension factor (Canivez & Watkins, in press). All things considered, we regarded Similarities a good indicator of g within the context of the WISC-V, as per Gignac (2014a) in the context of the WAIS-IV. However, for the purposes of robustness analyses, some re-testing was performed with Similarities as an indicator of g_c.

Finally, Processing Speed is measured within the WISC-V with three subtests: Symbol Search (SS), Coding (CD), and Cancellation (CA). According to the bifactor model tested by Canivez and Watkins (in press), all three of these subtests are good indicators of Processing Speed, independently of the effects of g.

2.3. Data analysis

All analyses were conducted with Amos 21 (Arbuckle, 2012). As can be seen in Fig. 1, the association between g_f and WMC was estimated with a correlated two-factor model, first excluding the PS subtest (panel A), in order to replicate Gignac (2014a), then including PS as an indicator of WMC (panel B) to extend Gignac (2014a). Next, to