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The relationship between working memory and intelligence in children: Is the scoring procedure important?

David Giofrè [a,*,1], Irene C. Mammarella [b]

[a] Department of General Psychology, University of Padova, Italy
[b] Department of Developmental and Social Psychology, University of Padova, Italy

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ABSTRACT

Different procedures have been proposed for scoring working memory (WM) tasks. The Absolute Credit Score (ACS) only considers performance in perfectly recalled trials, while the Partial Credit Score (PCS) considers imperfectly recalled ones too. Research indicates that different relationships between WM and general intelligence (the *g*-factor) may emerge using the ACS or the PCS. We reanalyzed the ACS and PCS obtained in a sample of 176 children in the 4th and 5th grades, and found that the PCS strengthened the relationship between WM and intelligence, and the relationships between visuospatial short-term memory (STM-VS), active WM and intelligence. When the number of items to be remembered (set size) was considered, however, the PCS only strengthened the relationship between STM-VS, active WM and intelligence in the case of larger set sizes. Practical and theoretical implications of these findings are discussed.

1. Introduction

Working memory and intelligence are closely-related constructs. Working memory (WM) is a limited-capacity system that enables information to be stored temporarily and manipulated (Baddeley, 2000). Intelligence is the ability to reason, plan, solve problems, think abstractly, understand complex ideas, learn quickly, and learn from experience (Gottfredson, 1997).

Intelligence and WM have both been linked to important outcomes. On the one hand, intelligence is related to academic and occupational achievements (Deary, Strand, Smith, & Fernandes, 2007; Schmidt & Hunter, 2004). On the other, a large body of research has shown that WM predicts success in school-related tasks such as reading comprehension (Carretti, Borella, Cornoldi, & De Beni, 2009), mental calculation (Caviola, Mammarella, Cornoldi, & Lucangeli, 2009), mathematical problems (Alloway & Passolunghi, 2011), multi-digit operations (Heathcote, 1994), and achievement in mathematics (Passolunghi, Mammarella, & Altoè, 2008) and geometry (Giofrè, Mammarella, Ronconi, & Cornoldi, 2013). Intelligence and WM are closely related and share a conspicuous portion of the variance (e.g., Engle, Tuholski, Laughlin, & Conway, 1999; Giofrè, Mammarella, & Cornoldi, 2013).

The very close relationship between WM and intelligence raises the question of whether or not the two constructs overlap. Initial evidence seemed to indicate that WM and intelligence were very closely related (Kyllonen & Christal, 1990) and almost isomorphic (e.g., Colom, Abad, Rebollo, & Shih, 2005). These findings were questioned when it came to adults, however. In fact, a meta-analysis showed a correlation of $r = .48$ between WM and intelligence (Ackerman, Beier, & Boyle, 2005), though the correlation between latent variables is typically higher, $r = .72$ (Kane, Hambrick, & Conway, 2005). In children too, there is evidence of WM and intelligence being separable (e.g., Engel De Abreu, Conway, & Gathercole, 2010), and suggesting that only about 50–60% of the variance is shared, while a portion of the variance does not appear to be

* Corresponding author at: Department of General Psychology, University of Padova, Via Venezia, 8, 35131 Padova, Italy. Tel.: +39 049 827 6617.
E-mail address: david.giofre@gmail.com (D. Giofrè).
[1] David Giofrè is now at the Department of Human Science, University of Urbino (Italy).

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shared by these two constructs (e.g., Giofrè, Mammarella, & Cornoldi, 2013). This incomplete overlap between WM and intelligence seems to indicate that the two constructs are distinguishable and not isomorphic (Conway, Kane, & Engle, 2003).

The literature also suggests a partial independence between WM and intelligence. For example, children with learning disabilities typically have WM difficulties despite being normally intelligent (e.g., Swanson & Siegel, 2001; see also Cornoldi, Giofrè, Orsini, & Pezzuti, 2014); and children with ADHD may struggle with WM tasks despite revealing a high level of intelligence (Martinussen, Hayden, Hogg-Johnson, & Tannock, 2005; see also Cornoldi, Giofrè, Calgaro & Stupiggia, 2013). It has been demonstrated, moreover, that WM – not intelligence – is the best predictor of literacy and numeracy (e.g., Alloway & Alloway, 2010), various mathematical skills (Träff, 2013), and academic achievement in geometry (Giofrè, Mammarella, & Cornoldi, 2014). Overall, this evidence converges in indicating that WM and intelligence may provide important, different information on children's cognitive functioning.

It is crucially important to understand the structure of WM when examining the relationship between WM and intelligence. The most classical, so-called tripartite model of WM was first proposed by Baddeley and Hitch (1974). This model involves a central executive responsible for controlling resources and monitoring information-processing across information domains. The storage of information is mediated by two domain-specific slave systems for short-term memory (STM), i.e., the phonological loop (used for the temporary storage of verbal information), and the visuospatial sketchpad (specialized in the recall of visual and spatial representations). Another model distinguishes between a storage component (typically characterized as a STM component) and a processing component, suggesting that WM processing capacity is limited by controlled attention (Engle et al., 1999). Other authors favor a unitary view of WM (Pascual-Leone, 1970), while some researchers have suggested that WM is even more articulated (e.g., Mammarella, Borella, Pastore, & Pazzaglia, 2013; Mammarella, Pazzaglia, & Cornoldi, 2008). Using different WM measures, two studies have shown that the tripartite model obtains the best fit in children (Alloway, Gathercole, & Pickering, 2006; Giofrè, Mammarella, & Cornoldi, 2013).

Alongside research on the structure of WM, there is also debate on which WM component is the best predictor of intelligence in children. Several studies have been conducted on the relationship between the various sub-components of WM and intelligence, with mixed results. Engel De Abreu et al. (2010) studied young children, for example, and found WM, STM and fluid intelligence related but separate constructs, and WM proved the best predictor of intelligence. In a study on children in kindergarten, on the other hand, Hornung, Brunner, Reuter, and Martin (2011) showed that, once the shared variance between STM and WM had been taken into account, only STM explained a significant portion of the variance in intelligence. Using the WISC-IV, another study on children with typical development showed that the relationship between WM and intelligence was stronger the greater the cognitive control required to complete a task (Cornoldi, Orsini, Cianci, Giofrè, & Pezzuti, 2013) (this does not seem to apply to children with ADHD, however; see Cornoldi, Giofrè, Calgaro, & Stupiggia, 2013). It was recently demonstrated, moreover, that only active WM and visuospatial short-term memory (STM-VS) correlated significantly with intelligence, while verbal short-term memory (STM-V) did not (Giofrè, Mammarella, & Cornoldi, 2013).

It is worth noting, however, that the above-mentioned studies adopted different scoring methods, and the scoring procedure seems to be crucial when testing different models of WM and how it relates with intelligence. Research on adults found that the Partial Credit Score (PCS), which stresses the importance of information obtained with the most difficult (longest) lists of items to recall, may emphasize the role of STM in explaining human intelligence (Unsworth & Engle, 2006, 2007). According to Unsworth and Engle (2006, 2007), the correlation between active WM and intelligence does not change as a function of the length of lists, but the correlation between simple STM and intelligence does. The PCS contains the same information as the Absolute Credit Score (ACS), which only measures performance in perfectly recalled trials, plus additional information obtained from lists of items that were not perfectly recalled. In adults at least, STM and WM seem to predict higher-order cognitive abilities equally well when the variability emerging from larger sets of items is considered (Unsworth & Engle, 2007).

In previous research, a sequential analysis was used to further investigate the influence of the scoring procedure when using sets of items of different sizes. Sequential analysis enabled the relationship with intelligence for each set size used in WM tasks to be controlled after taking the effect seen with previous set sizes into account (Salthouse & Pink, 2008), the goal of the analysis being to investigate whether each subsequent set size could explain intelligence over and above the effect of the previous one. This procedure is also useful for investigating the influence of the length of lists (as conceptualized by Unsworth & Engle, 2006) or the level of complexity (as conceptualized by Salthouse & Pink, 2008) of items to recall. Using sequential analysis, it was demonstrated that a strong influence of intelligence emerged for smaller sets of items, which would indicate that the relationship between WM and intelligence is independent of the amount of information to retain. To our knowledge, no research has been conducted in children on the effects of the scoring procedure on the relationship between WM and intelligence when lists of different lengths are recalled.

The primary aim of the present study was to see whether, and to what extent, the results obtained using two different scoring procedures could affect the relationship between various WM subcomponents and intelligence in children. One hypothesis is that the PCS stresses the influence of STM on intelligence, but has only a moderate impact on WM. Unlike previous researchers, we drew a distinction between the two verbal and visuospatial subcomponents of STM (i.e., the STM-V and the STM-VS) to investigate whether the scoring procedure has a different impact on the relationship between STM-V, STM-VS and intelligence. We additionally aimed to quantify any differences due to the different scoring procedures adopted in terms of the explained variance in intelligence.

If the scoring procedure affects the relationship between WM and intelligence, then why is this so? A further aim of this