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The structure of working memory and how it relates to intelligence in children

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

[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

This study explored the structure of working memory, and its relationship with intelligence in 176 typically-developing children in the 4th and 5th grades at school. Different measures of working memory (WM), and intelligence (*g*) were administered. Confirmatory factor analyses showed that WM involves an attentional control system and storage aspects that rely on domain-specific verbal (STM-V) and visuospatial (STM-VS) resources. The structural equation models showed that WM predicts a large portion (66%) of the variance in *g*, confirming that the two constructs are separable but closely related in young children. Findings also showed that only WM and STM-VS are significantly related to *g*, while the contribution of STM-V is moderate. Theoretical implications for the relationship between WM and *g* are discussed.

1. Introduction

Working memory (WM) is a limited-capacity system that enables information to be temporarily stored and manipulated (Baddeley, 2000). It is involved in complex cognitive tasks such as reading comprehension (Borella, Carretti, & Pelegrina, 2010; Carretti, Borella, Cornoldi, & De Beni, 2009; Daneman & Merikle, 1996) and arithmetical problem solving (Passolunghi & Mammarella, 2010, 2012; Passolunghi & Pazzaglia, 2004). Intelligence is the ability to reason, plan, solve problems, think abstractly, understand complex ideas, learn quickly, and learn from experience (Gottfredson, 1997).

Various models of WM have been suggested. We will discuss them here with reference to the different models presented in the current study. The most classical model (here called tripartite) was originally proposed by Baddeley and Hitch (1974). In this model the central executive (or working memory) is responsible for controlling the resources and monitoring information-processing across informational domains. In addition, the storage of information is mediated by two domain-specific slave systems (or short-term memory, STM), i.e., the phonological loop (used for the temporary storage of verbal information), and the visuospatial sketchpad (specialized in recalling visual and spatial representations). This model has met with a broad consensus (Baddeley, 2012), and further developments of the model (Baddeley, 2000) have maintained the distinction between a modality-independent component and modality-dependent verbal and visuospatial components of STM.

An alternative approach (modality-dependent model) does not include the distinction between short-term memory and WM. The model is based only on the assumption that WM is supported by two separate sets of domain-specific resources for handling verbal and visuospatial information (e.g., Shah & Miyake, 1996), each of which would be independently capable of manipulating the information and keeping it active (i.e., readily accessible). Research on adults supports this distinction (Friedman & Miyake, 2000).

* Corresponding author at: Department of General Psychology, University of Padova, via Venezia 8, 35131, Padova, Italy.
E-mail address: david.giofre@gmail.com (D. Giofrè).

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A different approach (modality-independent model) distinguishes between a storage component (typically characterized as a STM component) and a processing component, and suggests that WM processing capacity is limited by controlled attention (Engle, Tuholski, Laughlin, & Conway, 1999). Working memory tasks are considered the result of the joint activity of the storage and processing functions (e.g., Engle et al., 1999). This model and the tripartite Baddeley and Hitch (1974) model share the distinction between a central component for coordinating ongoing information processing (called controlled attention and central executive, respectively) and the component(s) for storing information in subsystems. The hypothesis that different components can be distinguished within WM has met with criticism, however. In particular, other authors have argued that STM and WM are hardly distinguishable (e.g., Martínez et al., 2011) and suggested a unitary model of WM, especially in the case of children (e.g., Pascual-Leone, 1970). Whether or not WM and STM reflect the same or different factors is still being debated (e.g., Colom, Rebollo, Abad, & Shih, 2006).

Regarding the structure of WM in children, it is not clear to what extent models proposed for adults can be applied to children too. As already mentioned, some authors favour a unitary view (Pascual-Leone, 1970), some (e.g., Engel De Abreu, Conway, & Gathercole, 2010) support a distinction between STM and WM (i.e., a modality-independent model), and others (e.g., Cornoldi & Vecchi, 2003; Mammarella, Pazzaglia, & Cornoldi, 2008) have suggested that WM is even more articulated. Finally, Alloway, Gathercole, & Pickering (2006) claimed that the tripartite model (Baddeley & Hitch, 1974) is the most appropriate across various age ranges.

Understanding the structure of WM is crucial when it comes to examining the relationship between WM and intelligence, in both adults and children. Research indicates that WM and intelligence are separable but closely-related constructs (Engle et al., 1999). For instance, 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). This incomplete overlap suggests that the two constructs are not isomorphic (Conway, Kane, & Engle, 2003) and that the relationship between them needs to be further elucidated.

In particular, research on children has produced less robust evidence concerning the relationship between intelligence and WM. It has been argued, for example, that WM, not intelligence, is the best predictor of literacy and numeracy (Alloway & Alloway, 2010), and that child prodigies may have only a moderately high level of intelligence, but perform extremely well in WM (Ruthsatz & Urbach, 2012). Such evidence further supports the conviction that WM and intelligence are separable, but more evidence is needed to confirm this.

In addition, studies on the relationship between STM, WM and intelligence in children often have their limitations. Firstly, only one task (e.g., Raven) has often been used to assess intelligence, whereas performance in different measures (preferably using different formats) should be considered to reduce the specific effects of a given test and treat intelligence as a latent construct (Süß & Beauducel, 2005). Secondly, not all studies have distinguished between (verbal and spatial) STM and WM, making it impossible to compare the different models used. Thirdly, the results of many studies may have been biased by the use of the absolute credit score for WM tasks: this score only considers the number of trials completed perfectly, whereas it might be better to take partial recall into account too in the most difficult trials to reflect the maximum level of performance a person may reach when WM is engaged in highly-demanding tasks. The absolute credit score is appropriate in clinical settings, while the partial credit score is more reliable and appropriate in correlational studies (Conway et al., 2005; Friedman & Miyake, 2005; Unsworth & Engle, 2007), as it results in higher correlations with criterion measures than does the absolute credit score method.The scoring procedure seems to be particularly important when testing different models of WM. In adults at least, the partial credit score, taking into account also the performance in the most difficult longest lists, may emphasize the role of STM in explaining human intelligence (Unsworth & Engle, 2007). In fact, the correlation between WM and intelligence does not change as a function of list length but the correlation between simple STM and intelligence does change. Indeed, the partial credit score contains the same information as the absolute credit score method plus additional information from items on lists that were not perfectly recalled. Importantly, STM and WM, at least in adults, seem to equivalently predict higher order cognitive abilities when the variability from long list lengths is considered (Unsworth & Engle, 2007).

The fact that STM and WM are predicting intelligence to the same extent, at least in adults, is consistent with the claim advanced by some researchers that STM accounts for the relationship between WM and intelligence (Chuderski, Taraday, Nęcka, & Smoleń, 2012; Colom, Abad, Quiroga, Shih, & Flores-Mendoza, 2008; Colom, Abad, Rebollo, & Shih, 2005; Krumm et al., 2009). However, this claim has been questioned both in general and, in particular, in the developmental literature (e.g., Engel De Abreu et al., 2010).

Be that as it may, further light needs to be shed on the relationship between STM, WM and intelligence in children. There is some evidence of the WM component having a stronger relationship with intelligence than the STM components. This impression has been influenced by original work provided by Engle and co-authors of the residual variance in WM reflecting controlled processing (once the STM component has been partialled out), which is uniquely linked to general fluid intelligence (Engle et al., 1999). To give an example, Engel De Abreu et al. (2010) studied young children, and found WM, STM and fluid intelligence related but separate constructs, and WM was the best predictor of intelligence. Conversely, Hornung, Brunner, Reuter, and Martin (2011), again in a study on young children, that once the storage component had been taken into account, only STM explained a significant portion of the variance in intelligence. Further studies are therefore needed to clarify the pattern of the relationships between these constructs.

In the present research, we explored the nature of the relationship between STM, WM and intelligence. These aspects were examined in 4th- and 5th-graders because their ages represent important transitions associated with wide mind reorganisations and, therefore, are particularly appropriate for emphasizing the relationship between different aspects of WM and intelligence (see Demetriou et al., 2013). In particular, we examined: i) different models of