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Working memory and fluid intelligence in young children

Pascale M.J. Engel de Abreu [a,*], Andrew R.A. Conway [b], Susan E. Gathercole [c]

[a] University of Oxford, UK
[b] Princeton University, USA
[c] University of York, UK

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ABSTRACT

The present study investigates how working memory and fluid intelligence are related in young children and how these links develop over time. The major aim is to determine which aspect of the working memory system—short-term storage or cognitive control—drives the relationship with fluid intelligence. A sample of 119 children was followed from kindergarten to second grade and completed multiple assessments of working memory, short-term memory, and fluid intelligence. The data showed that working memory, short-term memory, and fluid intelligence were highly related but separate constructs in young children. The results further showed that when the common variance between working memory and short-term memory was controlled, the residual working memory factor manifested significant links with fluid intelligence whereas the residual short-term memory factor did not. These findings suggest that in young children cognitive control mechanisms rather than the storage component of working memory span tasks are the source of their link with fluid intelligence.

1. Introduction

In recent years there has been substantial evidence that fluid intelligence and working memory are closely related (Colom, Flores-Mendoza, & Rebollo, 2003; Conway, Cowan, Bunting, Therriault, & Minkoff, 2002; Cowan et al., 2005; Engle, Tuholski, Laughlin, & Conway, 1999; Kane et al., 2004; Oberauer, Schulze, Wilhelm, & Süß, 2005; Unsworth, Redick, Heitz, Broadway, & Engle, 2009). Although researchers generally agree on the existence of such a relationship, the underlying nature of the association remains an issue of controversy. Furthermore, the vast majority of studies have focused on adults, and it remains to be seen whether the findings extend to children. The main aim of the present study was to explore the development of working memory and fluid intelligence in a population of young children in order to clarify the relationship between these two aspects of fluid cognition.

* Corresponding author. EMACS Research Unit, University of Luxembourg, L-7201 Walferdange, Luxembourg.
E-mail address: Pascale.Engel@uni.lu (P.M.J. Engel de Abreu).

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1.1. Definition of the key concepts

Fluid intelligence (Gf) is a complex cognitive ability that allows humans to flexibly adapt their thinking to new problems or situations. The concept has been defined by Cattell (1971) as: "an expression of the level of complexity of relationships which an individual can perceive and act upon when he does not have recourse to answers to such complex issues already sorted in memory" (Cattell, 1971, p. 99). In other words, Gf can be thought of as the ability to reason under novel conditions and stands in contrast to performance based on learned knowledge and skills or crystallized intelligence (Haavisto & Lehto, 2005; Horn & Cattell, 1967). Gf is generally assessed by tasks that are nonverbal and relatively culture-free.

Working memory (WM) has been described as a system for holding and manipulating information over brief periods of time, in the course of ongoing cognitive activities. Most theorists in the field agree that WM comprises mechanisms devoted to the maintenance of information over a short period of time, also referred to as short-term memory (STM), and processes responsible for cognitive control that regulate and coordinate those maintenance operations (Baddeley, 2000;

Cowan et al., 2005; Engle, 2010; Engle, Kane, & Tuholski, 1999; Engle, Tuholski, Laughlin, & Conway, 1999). WM is often assessed by complex span tasks that involve the simultaneous processing and storage of information (Daneman & Carpenter, 1980). An example of such a task is counting span, in which participants are asked to count a particular class of items in successive arrays and to store at the same time the number of target items in each array (Case, Kurland, & Goldberg, 1982). These complex span measures stand in contrast to simple span tasks that require only the storage of information with no explicit concurrent processing task. A typical simple span task is digit span, requiring the immediate recall of lists of digits.

Although STM and WM are theoretically distinct and sometimes separately assessed, no single task is a pure measure of either construct (Conway, Cowan, Bunting, Therriault, & Minkoff, 2002; Conway, Jarrold, Kane, Miyake, & Towse, 2008; Engle, Tuholski, et al., 1999). Even a seemingly simple task such as digit span is likely to involve cognitive control mechanisms. In a recent study, Unsworth and Engle (2006) showed that a simple span task with long lists of item taps the same controlled retrieval mechanism as complex span tasks. The authors argue that items from the end of a long list are retrieved from a capacity-limited STM store (or primary memory), whereas items from the beginning of the list which have been displaced from the limited capacity STM store are retrieved via a controlled search of secondary memory. Also, complex span tasks rely on simple storage as well as cognitive control mechanisms (Bayliss, Jarrold, Gunn, & Baddeley, 2003; La Pointe & Engle, 1990). Thus, simple and complex span tasks are likely to tap both storage and cognitive control, to differing degrees: whereas complex span tasks primarily reflect cognitive control and secondary storage, simple span measures are most sensitive to storage and depend less on cognitive control (Conway, Macnamara, Getz, & Engel de Abreu, in preparation; Kane et al., 2004; Unsworth & Engle, 2006).

The balance of these contributions to simple and complex span tasks may change with development. The efficiency of processing improves as children get older (Case et al., 1982); simple span tasks might therefore rely more heavily on cognitive control processes in younger than in older children or in adults (Engle, Tuholski, et al., 1999). If this is the case, simple and complex span tasks should be more closely associated in children than in adults, due to the common contribution of cognitive control mechanisms. Consistent with this position, Hutton and Towse (2001) found that simple and complex span tasks loaded on the same factor in 8- and 11-year-olds. In contrast, other studies suggest that simple and complex span tasks tap distinct but associated underlying constructs in developmental populations (Alloway, Gathercole, & Pickering, 2006; Alloway, Gathercole, Willis, & Adams, 2004; Gathercole, Pickering, Ambridge, & Wearing, 2004; Kail & Hall, 2001; Swanson, 2008).

1.2. Links between working memory and fluid intelligence

Many studies have shown that in adults, Gf and WM are strongly linked (Colom et al., 2003; Conway et al., 2002; Cowan et al., 2005; Engle, Tuholski, et al., 1999; Kane et al., 2004). The underlying nature of the association is, however, not fully understood. According to Engle, WM and Gf both rely on attentional control mechanisms (Engle 2010). In Gf tasks cognitive control is required to analyze problems, monitor the performance process, and adapt the resolution strategy as performance proceeds. In a similar way, cognitive control might be needed in WM tasks in order to maintain memory representations in an active state in the face of interference. A theoretically different account of the Gf–WM link has been proposed by Colom, Abad, Quiroga, Shih and Flores-Mendoza (2008). They argue that STM storage rather than cognitive control accounts for the relationship between WM and Gf.

Supporting evidence for both positions exists. In a latent variable study, Engle, Tuholski, et al. (1999) have shown that when the common STM and WM variance was removed, the WM residual factor was related to Gf, whereas the STM residual was not. Conway et al. (2002) and Kane et al. (2004) reported similar findings, indicating that the cognitive control demands rather than the storage component of WM span tasks are the source of the link with Gf. In contrast, Colom and colleagues have consistently found that individual differences in Gf are significantly associated with both STM and WM (Colom, Flores-Mendoza, Quiroga, & Privado, 2005; Colom, Rebollo, Abad, & Shih, 2006; Colom et al., 2008). In some of these studies STM was identified as a stronger predictor of Gf than WM, providing support to their position that short-term storage and not cognitive control mechanisms is responsible for the link between WM and Gf. One explanation of the discrepancies across these and other studies is that the degree to which STM and WM appear to be correlated or distinct depends on the particular tasks employed. The use of different tasks by different research groups therefore confounds direct comparisons of results.

The relationship between WM and Gf in children has been less intensively investigated (see Fry & Hale, 2000 for a review), and the few studies that exist generally agree that WM and Gf are strongly related but distinct constructs (Alloway et al., 2004; Fry & Hale, 2000). However, most of these studies do not address whether WM as a short-term storage system or as a cognitive controlling device is making significant contributions to children's fluid intelligence. In a recent latent variable study on 6- to 9-year-olds, Swanson (2008) found that when controlling for the correlations between WM and STM, the residual WM factor, but not STM, predicted Gf. A similar result was obtained by Bayliss, Jarrold, Baddeley, Gunn, and Leigh (2005). Importantly, in contrast to Swanson (2008), not only WM but also STM accounted for unique variance in Gf (see also Tillman, Nyberg, & Bohlin, 2008). In another developmental study the WM residual factor failed however to manifest significant links with Gf (Bayliss et al., 2003).

1.3. The present study

The purpose of the present study was to explore the underlying nature of the relationship between WM, STM, and Gf in 5- to 9-year-old children. The study had two major aims: first, it explored whether simple and complex span tasks are more closely associated in younger children than in older children or in adults, potentially because of the contribution of cognitive control mechanisms in assessments of STM in younger children (Engle, Tuholski, et al., 1999; Hutton & Towse, 2001). Second, the study investigated whether the pattern of results favors either the proposal that cognitive