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How storage and executive functions contribute to children's reading comprehension

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ABSTRACT

In the current study we investigated the contribution of storage and separate measures of executive functions to reading comprehension in Dutch 5th graders, while controlling for word recognition and vocabulary. In addition we investigated the relationship between this model and working memory as assessed with a listening span task–which reflects an integrated measure of both storage and executive functions.

Regression analysis revealed that word recognition, vocabulary, cognitive flexibility and listening span task performance contributed directly to reading comprehension. Adding the listening span task to the model led to a change in the beta-values of storage, inhibition and cognitive flexibility, indicating that these variables shared variance with listening span task performance. A second regression analysis confirmed this finding: storage, inhibition and cognitive flexibility contributed to listening span task performance, and hence indirectly to reading comprehension.

Together, these findings highlight the contribution of storage and executive functions to children's reading comprehension.

1. Introduction

Reading comprehension is the product of a complex integration of multiple skills. First, it depends on the ability to efficiently decode words (Lyon, 1995; Torgesen, 2000) as that allows the reader to draw word representations from the text. Consequently, children with poor decoding skills commonly experience difficulties with reading comprehension (Shankweiler, 1999; Torgesen, 2000). Nevertheless, reading comprehension difficulties cannot always be attributed to difficulties in word decoding. A considerable number of children have reading comprehension difficulties despite having an age-appropriate level of word decoding (Cain & Oakhill, 2006; Nation & Snowling, 2004; Yuill & Oakhill, 1991). As proposed by the lexical quality hypothesis (Perfetti & Hart, 2002) and supported by several other studies, reading comprehension performance also depends on language skills, such as syntactic (Cutting & Scarborough, 2006; Muter, Hulme, Snowling, & Stevenson, 2004; Oakhill & Cain, 2011) and semantic representations (Cutting & Scarborough, 2006; Nation & Snowling, 2004; Torgesen, 2000). In addition, working memory—the ability to store information while simultaneously carrying out processing operations—is a well-established predictor of reading comprehension performance (for meta-analyses, see Carretti, Borella, Cornoldi, & De Beni, 2009; Daneman & Merikle, 1996). It is thought that working memory is needed for reading comprehension to integrate stored text representations with incoming information (Daneman & Carpenter, 1980).

A commonly applied working memory model in the reading comprehension literature is the one by Baddeley and Hitch (1974). According to that model, verbal information is stored in the phonological loop, and visual and spatial information is stored in the visuospatial sketchpad. The model includes a central executive that controls the transfer of information from and to these two storage systems. In other words, the central executive controls the processing of information (see also Baddeley, 2000). Though the central executive is presented as a unitary system, it has been proposed that it may reflect or is linked to multiple, domain-general, executive functions (Baddeley, 1986, 1996; Baddeley & Della Sala, 1996; Baddeley, Emslie, Kolodny, & Duncan, 1998). These include the three core executive functions updating (Morris & Jones, 1990), inhibition, (Baddeley et al., 1998; Borella, Carretti, & Pelegrina, 2010; Cain, 2006; De Beni & Palladino, 2000) and cognitive flexibility, and higher-order executive functions, such as planning (Baddeley, 1996). In the past decades, researchers investigating individual differences in reading comprehension have frequently used Daneman and Carpenter, (1980) listening span task to assess working memory. The listening span task is an integrated working memory task which reflects multiple components including both storage (recalling sentence final words) and processing of information (sentence judgment) in concurrence with Baddeley's model (2000). It is referred to as domain-specific as it assesses working memory within

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the language domain, and taps into processes closely related to reading comprehension.

Several studies have investigated whether individual differences in reading comprehension are best explained by the processing aspects or by the storage aspects of working memory tasks. There is substantial evidence that tasks measuring processing in addition to storage, such as the listening span task, are better indicators of reading comprehension performance than tasks assessing the temporary storage of information only, such as the word span task (Daneman & Carpenter, 1980; De Beni & Palladino, 2000; Swanson & Berninger, 1995). These results have been taken to suggest that individual differences in reading comprehension are mainly associated with the processing component of the listening span task. Regarding Baddeley's model (2000), this entails that individual differences relevant to reading comprehension would lie in the central executive component. As the central executive may reflect or may be linked to multiple, domain-general, executive functions (Baddeley, 1986, 1996; Baddeley et al., 1998) this suggests that individual differences relevant to reading comprehension could lie in variation in domain-general, executive functions, which may be tapped by using measures such as the listening span task. It is, however, unclear if and which separate measures of executive functions such as inhibition, updating, cognitive flexibility and planning are encompassed by the listening span task.

Two areas of research speak to whether these domain-general executive functions contribute to individual variation in reading comprehension. Firstly, largely separate studies have shown that different executive functions explain variance in reading comprehension performance. For instance, updating—the ability to replace no longer relevant information with new, more relevant information in working memory (Morris & Jones, 1990)—was found to contribute to reading comprehension performance in children (Barnes, Raghubar, Faulkner, & Denton, 2014; Iglesias-Sarmiento, López, & Rodríguez, 2015; Pelegrina, Capodieci, Carretti, & Cornoldi, 2014). Similarly, inhibition—the ability to suppress automatic reactions, ignore irrelevant information or suppress no longer relevant information (Friedman & Miyake, 2004)—has also been shown to contribute to reading comprehension performance in children (Barnes, Faulkner, Wilkinson, & Dennis, 2004; Kieffer, Vukovic, & Berry, 2013). Furthermore, cognitive flexibility—the ability to shift between multiple operations and mental states (also referred to as task switching or shifting; Anderson, 2002; Diamond, 2013)—was found to explain variance in children's reading comprehension (Colé, Duncan, & Blayne, 2014; Kieffer et al., 2013). Moreover, planning—the ability to decide which tasks are necessary to efficiently reach and complete a goal (Cartwright, 2009)—has been shown to explain variation in reading children's comprehension performance (Cutting, Materek, Cole, Levine, & Mahone, 2009; Locascio, Mahone, Eason, & Cutting, 2010; Sesma, Mahone, Levine, Eason, & Cutting, 2009).

Secondly, in a small number of recent studies an indirect relation between inhibition and children's reading comprehension, via working memory tasks, has been reported. While performing working memory tasks similar to Daneman and Carpenter, (1980)'s listening span task, children with difficulties in reading comprehension were more likely to recall target words from previous trials that should have been eliminated from memory (de Beni & Palladino, 2000; Borella et al., 2010; Cain, 2006). These findings have been interpreted as a deficiency in inhibitory mechanisms, which has been suggested to explain variation in working memory task performance, which in turn has been put forth in explaining variance in reading comprehension (Cain, 2006). To our knowledge, indirect (i.e., via working memory tasks) contributions of updating, cognitive flexibility and planning, to reading comprehension, have not been investigated.

In summary, domain-specific working memory, commonly assessed with a listening span task, has been found to be a significant predictor of variation in reading comprehension even when word recognition and language ability are taken into account. Previous studies have shown that such working memory tasks, which reflect processing in addition to storage, are better predictors of reading comprehension performance than storage tasks, indicating that it is the general processing component tapped by working memory tasks that is important for reading comprehension, rather than the storage component (Daneman & Merikle, 1996; Cain, 2006). At the same time, previous work suggests that the general processing component, conceptualized as the 'central executive' in Baddeley's (2000) model, taps into several executive functions that may contribute to individual differences in reading comprehension as well. Indeed there are indications that executive functions may indirectly contribute to reading comprehension via working memory tasks. Moreover, a few studies have also found that executive functions directly contribute to reading comprehension performance.

Though the associations between working memory and reading comprehension are well documented, several issues remain to be investigated. First of all, as working memory is commonly measured with the domain-specific, integrated listening span, it is unclear how and if both storage and separate measures of executive functions relate to reading comprehension performance. Secondly, as it stands, a relation between different executive functions and reading comprehension has been reported repeatedly, but so far those relations have mostly been investigated in isolation in the sense that studies only included one executive function (except for Cutting et al., 2009; Locascio et al., 2010; Kieffer et al., 2013). Thirdly, it is unclear how both storage and separate measures of executive functions are encompassed by the listening span task, and therefore whether executive functions such as inhibition, cognitive flexibility and planning can explain unique individual variation in children's reading comprehension over and above variance explained by performance on the listening span task. A study including a separate storage measure, and several executive functions at the same time, while taking non-verbal cognitive ability, word recognition and vocabulary knowledge into account, is currently missing. With the current study we have attempted to fill this gap.

The current study included non-verbal cognitive ability, word recognition and vocabulary as control measures, a listening span to reflect an integrated construct of working memory, and a storage measure and separate measures of the executive functions' inhibition and cognitive flexibility, as well as the higher order executive function planning. Updating was not included as measures of updating are closely linked to measures of working memory (Miyake et al., 2000; Morris & Jones, 1990; Schmiedek et al., 2009; St. Clair-Thompson & Gathercole, 2006). The tasks measuring inhibition, cognitive flexibility and planning were selected based on the following criteria: 1) the contribution of verbal information was minimal, and 2) the measures were standardized tests that have previously been analyzed for content validity.

Non-verbal cognitive ability, word-recognition, vocabulary, storage and executive functions were expected to directly contribute to reading comprehension. The contribution of storage and executive functions was expected to decrease after accounting for performance on the listening span task. Additionally, storage, inhibition, cognitive flexibility and planning were expected to contribute to performance on the listening span (Baddeley, 1996; Baddeley et al., 1998; Borella et al., 2010; Cain, 2006; De Beni & Palladino, 2000), and hence indirectly to reading comprehension.

2. Method

2.1. Participants

A total of 123 Dutch fifth grade children were recruited from four elementary schools in The Netherlands. Four children were excluded from the sample because they scored below the 25% percentile on a standardized measure of non-verbal cognitive ability (Raven's Colored Progressive Matrices; Raven, Raven, & Court, 2003). Another two children were excluded because they failed to answer over 10% of the questions on the reading comprehension test. The remaining sample included 117 children, consisting of 62 boys (53%) and 55 girls aged