Cognitive Development xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Cognitive Development

journal homepage: www.elsevier.com/locate/cogdev

Behavioral performance and neural areas associated with memory processes contribute to math and reading achievement in 6-year-old children

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ARTICLE INFO

Keywords:
Working memory
Episodic memory
Math
Reading
Academic achievement
EEG

ABSTRACT

Associations between working memory and academic achievement (math and reading) are well documented. Surprisingly, little is known of the contributions of episodic memory, segmented into temporal memory (recollection proxy) and item recognition (familiarity proxy), to academic achievement. This is the first study to observe these associations in typically developing 6-year old children. Overlap in neural correlates exists between working memory, episodic memory, and math and reading achievement. We attempted to tease apart the neural contributions of working memory, temporal memory, and item recognition to math and reading achievement.

Results suggest that working memory and temporal memory, but not item recognition, are important contributors to both math and reading achievement, and that EEG power during a working memory task contributes to performance on tests of academic achievement.

1. Introduction

1. Observed variability in academic achievement has led to research on the contributions of various cognitive processes to academic success (e.g., St Clair-Thompson & Gathercole, 2006). Our current understanding of the connection between memory and academic skills, however, is lacking because of the literature's focus on one type of memory (i.e., working memory), rather than the multiple systems that comprise complex memory events. Academic achievement requires coordination between multiple complex cognitive systems (e.g. Bryce, Whitebread, & Szucs, 2015). Therefore, it is unlikely that one component of memory can solely explain the contribution of memory to academic achievement. The purpose of our study was to examine the contributions of various memory types (working memory, temporal memory, and item recognition) to performance on standardized measures of academic achievement in 6-year-old children. In order to gain further evidence for the importance of memory systems for academic achievement, we examined both behavioral and neural indices of working and episodic memory (EM). Our study expands on previous research by encompassing multiple components of memory at both behavioral and neural levels.

Working memory (WM) has been a central focus in the academic achievement literature. Many studies have examined the contribution of WM and WM systems on academic success (e.g., Bull, Espy, & Wiebe, 2008; Nation, Adams, Bowyer-Crane, & Snowling, 1999; Passolunghi, Caviola, De Angostini, Perin, & Mammarella, 2016). WM requires updating and maintenance of active information and has been found to contribute to reading achievement in children (Siegel, 1994). WM allows for

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http://dx.doi.org/10.1016/j.cogdev.2017.07.002
Received 5 October 2016; Received in revised form 26 June 2017; Accepted 18 July 2017

conceptualization and maintenance of words needed for comprehension (Baddeley, 2003; Siegel, 1994), and speed of reading comprehension (i.e. fluency; Ellis, 1996). Clearly, WM is an important factor in reading achievement. In addition to an association with reading achievement, WM has been connected to mathematics achievement (i.e. Lee & Bull, 2016). WM is needed for retrieval of numerical facts (Kaufmann, 2002), maintenance and updating of numerical representations and strategy (Bull & Lee, 2014; Geary, 1993).

One of the components of the WM model is the Episodic Buffer (EB; Baddeley, 2000). The EB is believed to aid in the process of sending and receiving information from EM (Baddeley, 2000). In a study examining classic components of WM (i.e., EB, visuospatial sketchpad, phonological loop, and central executive), the EB was reported to contribute to reading achievement (Nevo & Breznitz, 2010). This finding suggests that the EB contributes to academic achievement independent of the other components of WM. Recall that EB sends and retrieves information from EM; therefore, it is likely that EM is involved in academic achievement as well. In fact, emerging evidence suggests that the recollection component of EM contributes to some aspects of academic achievement over and above WM (Blankenship, O'Neill, Ross, & Bell, 2015). However, no study has considered both temporal memory (recollection proxy) and item recognition (familiarity proxy) measures when examining the relation between EM and academic achievement. We propose that EM plays an independent role in academic achievement.

As previously noted, EM may be divided into two components, recollection and familiarity (Yonelinas, 2002). Recollection allows for vivid re-experience of an event and its context during retrieval, whereas familiarity refers to a general sense of knowing that an event has occurred (Ghetti & Lee, 2013; Yonelinas, 2002). Given the characteristics of recollection and familiarity, tasks requiring retrieval of contextual information (e.g., temporal memory) are typically used as a proxy of recollection, while tasks excluding contextual retrieval (e.g., item recognition) are typically used as a proxy of familiarity (e.g., Yonelinas, 2002). While temporal memory and item recognition are more likely to elicit recollection and familiarity, respectively, these are not process pure measures of these constructs. In terms of development, children show improvements in recollection performance throughout middle childhood and into adolescence. Familiarity performance, however, stabilizes earlier, around age 8 (Ghetti & Angelini, 2008). There has been little research examining how the EM processes of recollection and familiarity are related to academic achievement in typically developing children. Mirandola, Del Prete, Ghetti, and Cornoldi (2011) examined recollection and familiarity in adolescents with and without reading difficulties. They found that the adolescents with reading difficulties displayed a deficit in recollection but not familiarity when compared to typical reading controls. These researchers did not consider other critical contributors to academic achievement, such as WM and intelligence (IQ). Additionally, they did not consider how recollection and familiarity relate to typical reading development. Other researchers have reported connections between recollection and academic achievement during middle childhood in typically developing children (Blankenship et al., 2015); however, no work has considered neural contributions of EM or familiarity.

Associations between recollection and math are rarely examined, but may be found indirectly through recall tasks (Stevenson & Newman, 1986). Yonelinas (2002) proposed that recall tasks elicit recollection more so than familiarity processes, especially if recall of contextual information is required (e.g., temporal memory; Yonelinas, 1994). This suggests that recognition is more reliant on familiarity, and recall is more reliant on recollection. No studies thus far have directly compared recollection and familiarity to math achievement. It is likely that recollection would contribute to math because of the effortful reliance on recall during mathematical calculations and problem solving. For example, when completing a math problem, retrieval of key facts and procedures related to solving the problem must be recalled in order to be successful. This recall process would likely rely on recollection processes, especially in young children who are just developing mathematical processes.

Many of the neural processes observed during math and reading performance are similar to those associated with WM and EM. As such, the frontal lobe activation observed during math (e.g., calculation) and reading (e.g., reading fluency) tasks is typically attributed to WM (e.g., King & Kutas, 1995; Metcalfe, Ashkenazi, Rosenberg-Lee, & Menon, 2013; Turkeltaub, Gareau, Flowers, Zeffiro, & Eden, 2003). In terms of EEG activity, alpha oscillations are typically correlated with WM performance in adults (Klimesch, 1999) and children (Wolfe & Bell, 2004). Similarly, temporal lobe activation during math and reading has been suggested to reflect explicit memory systems, which includes EM (Tulving, 2002; ; Turkletaub et al., 2003 ; Tulving, 2002; ; Turkletaub et al., 2003). With respect to oscillations, theta band activity is typically associated with EM in adults (Klimesch et al., 2001) and children (Blankenship & Bell, 2015). In academic achievement research, focus is often placed on another type of explicit memory, specifically semantic memory. Semantic memory differs from EM in that it does not involve contextual information, but rather factual information void of its context (Tulving, 1972). Factual information is key for being successful academically, but contextual information associated with EM is likely critical for acquiring math and reading abilities.

In order to fully understand how academic achievement operates, a comprehensive view of memory is necessary. We took this approach by examining the unique contributions of WM and the EM processes of item recognition and temporal memory to reading and math achievement, while controlling for the contributions of IQ. The contributions of WM and EM were considered at both behavioral and neural levels. Recollection and familiarity are related, but distinct EM processes. Understanding how memory relates to academic achievement behaviorally and neutrally may provide stronger evidence for the importance of various memory processes for academic achievement.

In sum, we examined the contributions of three memory processes to academic achievement in typically developing children. We focused on these processes in 6-year-old children because by age 6 most children have finished their first formal year of education, and thus will have had exposure to testing situations similar to the assessments given in our study. That being said, the constructs of interest tend to display continuity throughout middle childhood, so similar results may be found throughout this period. Furthermore, middle childhood is associated with increases in WM ability as well as improvements in use of encoding strategies, and thus EM performance (for review see Schneider and Ornstein (2015). Both academic exposure and EM ability makes middle