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Development of visual working memory and distractor resistance in relation to academic performance



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ABSTRACT

Visual working memory (VWM) enables active maintenance of goal-relevant visual information in a readily accessible state. The storage capacity of VWM is severely limited, often as few as 3 simple items. Thus, it is crucial to restrict distractor information from consuming VWM capacity. The current study investigated how VWM storage and distractor resistance develop during childhood in relation to academic performance in the classroom. Elementary school children (7- to 12-year-olds) and adults (total $N = 140$) completed a VWM task with and without visual/verbal distractors during the retention period. The results showed that VWM performance with and without distractors developed at similar rates until reaching adult levels at 10 years of age. In addition, higher VWM performance without distractors was associated with higher academic scores in literacy (reading and writing), mathematics, and science for the younger children (7- to 9-year-olds), whereas these academic scores for the older children (10- to 12-year-olds) were associated with VWM performance with visual distractors. Taken together, these results suggest that VWM storage and distractor resistance develop at a similar rate, whereas their contributions to academic performance differ with age.

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Introduction

Visual working memory (VWM) enables us to actively maintain visual information for a short period of time in a readily accessible state. VWM serves fundamental roles in many cognitive processes, as demonstrated by robust correlations with broad measures of intellectual ability such as complex reasoning, decision making, and goal-directed action (Baddeley, 2003; Fukuda, Vogel, Mayr, & Awh, 2010; Unsworth, Fukuda, Awh, & Vogel, 2014). One of the distinctive characteristics of VWM is its limited capacity; we can hold only up to 3 simple objects in VWM at a time (Luck & Vogel, 1997). There are two different views regarding whether VWM capacity is best described as a maximal number of items (Awh, Barton, & Vogel, 2007; Fukuda, Awh, & Vogel, 2010; Zhang & Luck, 2008) or as a fluid amount of mnemonic resources (Bays & Husain, 2008; Ma, Husain, & Bays, 2014), but both models share the view that behavioral performance is highly accurate for only a small amount of information (Luck & Vogel, 2013; van den Berg, Awh, & Ma, 2014).

VWM capacity increases with age during childhood (Cowan et al., 2005; Heyes, Zokaei, Van der Staaij, Bays, & Husain, 2012; Riggs, McTaggart, Simpson, & Freeman, 2006; Simmering & Perone, 2013). Riggs et al. (2006) examined how elementary school children's VWM capacity develops using a color change detection task. In this task, a small number of colored squares were briefly presented, followed by a short retention interval, and then a test array. Either the test array was identical to the sample array or one of the squares was a different color. The children simply reported whether a change was present or not. The estimated VWM capacity in this task was 1.52 colors for 5-year-olds, 2.89 for 7-year-olds, and 3.83 for 10-year-olds, suggesting that VWM capacity develops during childhood and reaches the adult level (i.e., 3 objects) by around 10 years of age. Adults can hold multi-feature items (e.g., a red square and a yellow rectangle) as well as single-feature items (e.g., a red square and a yellow square) in VWM, suggesting that the unit of VWM capacity is the integrated object rather than individual features (Luck & Vogel, 1997; but see also Jiang, Makovski, & Shim, 2009; Magnussen, Greenlee, & Thomas, 1996). Riggs, Simpson, and Potts (2011) found that even young children remember multi-feature items as well as single-feature items in much the same way as adults, supporting the integrated object view of VWM capacity. Thus, the unit of VWM capacity is developmentally invariant as VWM capacity increases to the adult level. Similar findings in the development of VWM capacity were shown across various VWM tasks, including a color array recognition task (Cowan et al., 2005; Simmering, 2012), a Corsi block task (Isaacs & Vargha-Khadem, 1989; Orsini, Schiappa, & Grossi, 1981), and a pattern recall task (de Ribaupierre & Bailleux, 1994; Wilson, Scott, & Power, 1987). Importantly, the development of VWM capacity stems from the increment of storage space, not from improvement in support processes such as mnemonic strategies, encoding speed, and increment of knowledge (Cowan, 2014; Cowan, AuBuchon, Gilchrist, Ricker, & Saults, 2011).

VWM capacity is severely limited, generally to as few as 3 simple items. This limitation means that efficient mechanisms are required to restrict distractor information from consuming the limited capacity and represent only the task-relevant objects. Previous studies showed that adult participants' VWM capacity is reduced when distractors are presented during encoding or retention periods (McNab & Dolan, 2014; McNab & Klingberg, 2008; Vogel, McCollough, & Machizawa, 2005). These findings suggest that VWM capacity is determined by at least two components: VWM storage (Cowan, Fristoe, Elliott, Brunner, & Saults, 2006) and distractor resistance (McNab & Dolan, 2014; Vogel et al., 2005). Previous studies revealed that children performed poorly compared with adults when they were presented with cognitive tasks with distractors (Cowan et al., 2006; Olesen, Macoveanu, Tegner, & Klingberg, 2007; Plude, Enns, & Brodeur, 1994). However, it is still unknown how distractor resistance develops during childhood, especially in relation to VWM storage. The current study first sought to investigate this question using the color array VWM task (Luck & Vogel, 1997).

There are two possibilities regarding the development of VWM storage and distractor resistance supported by research. The first is that the two VWM functions develop at the same time at the same rate. This is plausible because there is a strong relationship between working memory (WM) storage and the ability to restrict distractor information from consuming WM capacity. Several studies have

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