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The development of visual working memory capacity during early childhood

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ABSTRACT

The change detection task has been used in dozens of studies with adults to measure visual working memory capacity. Two studies have recently tested children in this task, suggesting a gradual increase in capacity from 5 years to adulthood. These results contrast with findings from an infant looking paradigm suggesting that capacity reaches adult-like levels within the first year. The current study adapted the change detection task for use with children younger than 5 years to test whether the standard version of the task was too difficult and may have underestimated children's capacity. Results showed that 3- and 4-year-olds could successfully complete this modified task and that capacity increased roughly linearly, from 2 or 3 items during this period to 3 or 4 items between 5 and 7 years. Furthermore, performance did not differ significantly between the modified version and a replication of the standard version with 5- and 7-year-olds. Thus, there is no evidence that previous research with the change detection task underestimated children's capacity. Further research is needed to understand how performance relates across the infant looking task and change detection to provide a more complete picture of visual working memory capacity over development.

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Introduction

Visual working memory (VWM) provides a critical foundation for our understanding of the visual world around us. As we move our eyes to survey our environment, VWM provides a bridge between the fleeting perceptual representation formed in a single fixation and our enduring long-term

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representation of familiar objects, people, and places. Without the ability to represent visual information in working memory during eye movements, our experience would be a series of disjointed snapshots. Decades of research have revealed that VWM has a severely limited capacity of just 3–5 simple items in young adults (Cowan, 2010). Beginning with Luck and Vogel's (1997) seminal article, the change detection task has been a common method for testing VWM capacity. In this task, a small number of items are briefly presented in a memory array. After a short delay, a test array is presented in which either all of the items match the memory array ("same" trials) or 1 item has changed ("different" trials). This array remains visible until the participant responds by pressing a key corresponding to his or her judgment of same or different. Capacity can be estimated from performance in this task using a formula proposed by Pashler (1988),¹ which subtracts the effect of "guessing" (i.e., responding different on no-change trials) from correct performance on change trials. Although dozens of studies have tested adults' capacity with this task, typically reported at 3 or 4 simple objects, only a few have tested the development of VWM capacity in this way.

Capacity is a concept of considerable interest within psychology because it has been proposed as the foundation for a range of intelligent behaviors, including language comprehension (e.g., Just & Carpenter, 1992), executive control in rule use (e.g., Marcovitch, Boseovski, Knapp, & Kane, 2010), and performance on standardized tests of scholastic performance (e.g., Cowan et al., 2005). For instance, Cowan et al. (2005) conducted a wide-ranging study in which capacity was estimated from numerous verbal and visual working memory tasks, all of which showed moderate to strong correlations with measures of working memory and standardized test scores. With regard to VWM specifically, capacity increased gradually over development, from approximately 3.5 items at 7 and 8 years, to 4.4 items at 9 and 10 years, to 4.8 items at 11 and 12 years, to 5.7 items for college students (note that estimates are averaged across two experiments reported by Cowan et al.). The estimates for adults in this study are slightly higher than those typically reported in the literature, but they follow from the estimates derived for children in the same task.

These findings suggest that capacity can provide an index of general cognitive ability, as measured by a range of tasks as well as strong continuity over development beginning during the grade school years. Riggs, McTaggart, Simpson, and Freeman (2006) expanded on Cowan et al. (2005) findings by testing younger children in the change detection task. They found similar increases at an earlier stage of development, with capacity estimated to be 1.52 items at 5 years, 2.89 items at 7 years, and 3.83 items at 10 years. Taken together, the studies by Cowan and colleagues and Riggs and colleagues suggest continuity of VWM from 5 years to adulthood.

Studies with infants, however, have revealed contradictory results. In a preferential looking task modeled after the Luck and Vogel (1997) change detection paradigm, Ross-Sheehy, Oakes, and Luck (2003) found that VWM capacity increased rapidly during early infancy, reaching adult-like levels by the end of the first year. In this task, infants were seated in front of two video displays, each containing a small number of items that blinked on and off over a 20-s trial. On the no-change display, the items remained the same after each blink (similar to "same" trials in change detection), whereas one item changed with each blink on the change display (similar to "different" trials in change detection). Capacity was estimated as the highest number of items per display at which infants showed a reliable preference for the change display. Ross-Sheehy and colleagues estimated capacity to be 1 item at 6.5 months, 3 or 4 items at 10.5 months, and at least 3 items at 12.5 months (12-month-olds were not tested beyond 3 items per display) using this change preference task, suggesting that capacity reached adult-like levels within the first year.²

Riggs et al. (2006) suggested three possible explanations behind the developmental inconsistency between the infant change preference task and the change detection task used with older children.

¹ Cowan (2001; see also Cowan et al., 2005) proposed a modified formula for tasks on which a single item is cued on test. This formula, which produces lower estimates than Pashler's (1988) formula, was used to calculate the results reported from Cowan et al. (2005); all other capacity estimates from change detection discussed here were calculated using Pashler's (1988) formula.

² Additional infant studies have been proposed to assess VWM capacity through other methods (e.g., Feigenson & Carey, 2003; Rose, Feldman, & Jankowski, 2001). However, these paradigms differ in critical ways from the change detection and change preference tasks discussed here, and they may rely on cognitive processes in addition to VWM (e.g., motor planning, episodic memory, long-term memory). Due to such differences, these studies are not included for comparison here.

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