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# Quantifying attentional effects on the fidelity and biases of visual working memory in young children



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### ABSTRACT

Attentional control enables us to direct our limited resources to accomplish goals. The ability to flexibly allocate resources helps to prioritize information and inhibit irrelevant/distracting information. We examined developmental changes in visual working memory (VWM) fidelity in 4- to 7-year-old children and the effects that a distracting non-target object can exert in biasing their memory representations. First, we showed that VWM fidelity improves from early childhood to adulthood. Second, we found evidence of working memory load on recall variability in children and adults. Next, using cues to manipulate attention, we found that older children are able to construct a more durable memory representation for an object presented following a non-target using a pre-cue (that biases encoding before presentation) compared with a retro-cue (that signals which item to recall after presentation). In addition, younger children had greater difficulties maintaining an item in memory when an intervening item was presented. Lastly, we found that memory representations are biased toward a non-target when it is presented following the target and away from a non-target when it precedes the target. These bias effects were more pronounced in children compared with adults. Together, these results demonstrate changes in attention over development that influence VWM memory fidelity.

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## Introduction

Navigating and problem solving in a dynamic environment requires maintaining and continually updating representations. Underlying these abilities are working memory and goal monitoring, which are in constant interaction with attentional mechanisms (Badre, 2011; Lenartowicz, Kalar, Congdon, & Poldrack, 2010). Visual working memory (VWM) is the ability that allows the maintenance of visual information in the absence of sensory input (Baddeley, 2003; Courtney, Ungerleider, Keil, & Haxby, 1997; Todd & Marois, 2004). During childhood, there is continued development of brain structures subserving these processes (Casey, Tottenham, Liston, & Durston, 2005). To fully understand the mechanisms of VWM, it is important to determine the sources contributing to developmental change. Although several prominent models in the adult cognitive neuroscience literature have focused on the nature of VWM limitations, few incorporate developmental constraints by applying these models to both adults and children.

VWM capacity is severely limited (Alvarez & Cavanagh, 2004; Baddeley, 1992; Bays, Catalao, & Husain, 2009; Cowan, 2010; Luck & Vogel, 1997). Classic studies with adults using change detection paradigms revealed a limit of three or four objects (or “slots”) (Awh, Barton, & Vogel, 2007; Luck & Vogel, 1997; for a recent review, see Luck & Vogel, 2013). Age-related improvement in capacity limits between 3 and 11 years of age suggests a slow gradual improvement over childhood (Cowan et al., 2005; Riggs, McTaggart, Simpson, & Freeman, 2006; Simmering, 2012). Prominent developmental theories embrace a slot-based model that assumes that objects are stored with high fidelity or forgotten completely and where changes over development encompass increases in the absolute storage capacity of the VWM system (Cowan, Morey, Chen, Gilchrist, & Sauls, 2008).

An alternative model suggests that although memory is a limited resource, it can be flexibly distributed among items, where some items can be maintained with high resolution and others at a lower resolution in memory. Recent studies, mostly with adults, have turned toward a continuous analog measure of memory by computing the variance of the responses around the actual value rather than the number of items to be remembered (Bays & Husain, 2008; for a recent review, see Ma, Husain, & Bays, 2014).

### *Biases of memory*

According to the resource model, memory representations are noisy reconstructions of the memoranda that are susceptible to distortions. In the adult VWM literature, there have been efforts to analyze and quantify the different sources of noise (e.g., Huang & Sekuler, 2010; Marshall & Bays, 2013; Sekuler & Kahana, 2007). These models attribute the imprecision of recalled information to systematic factors such as interference from previously encoded items and task-irrelevant information, in contrast to noise resulting from guessing due to inattention. In these studies, the parametric nature of the stimulus features enabled researchers to quantify the differential contributions of these various sources of error.

One source of error is long-term knowledge. Brady, Konkle, and Alvarez (2011) reviewed evidence for how representations in VWM are influenced by previous experiences, where prior expectations bias judgments. It has been proposed that there is a mechanism in visual processing that identifies objects and a second one that computes and stores their average properties, disposing details for efficiency (see, e.g., Alvarez, 2011). This bias can be conceptualized within a Bayesian framework of memory, where the prior serves as a representation of a weighted average of a memory trace (Hemmer & Steyvers, 2009). Indeed, Huang and Sekuler (2010) reported a prototype effect, where the current memory representation was pulled in the direction of an average feature representation of previously viewed stimuli. Similar reports of temporal dependence of VWM contents on previously viewed information have been demonstrated and quantified in various other contexts (Alvarez & Oliva, 2008, 2009; Fischer & Whitney, 2014; Haberman, Harp, & Whitney, 2009).

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