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# Seven-month-old infants chunk items in memory

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ABSTRACT

Although working memory has a highly constrained capacity limit of three or four items, both adults and toddlers can increase the total amount of stored information by "chunking" object representations in memory. To examine the developmental origins of chunking, we used a violation-of-expectation procedure to ask whether 7-month-old infants, whose working memory capacity is still maturing, also can chunk items in memory. In Experiment 1, we found that in the absence of chunking cues, infants failed to remember three identical hidden objects. In Experiments 2 and 3, we found that infants successfully remembered three hidden objects when provided with overlapping spatial and featural chunking cues. In Experiment 4, we found that infants did not chunk when provided with either spatial or featural chunking cues alone. Finally, in Experiment 5, we found that infants also failed to chunk when spatial and featural cues specified different chunks (i.e., were pitted against each other). Taken together, these results suggest that chunking is available before working memory capacity has matured but still may undergo important development over the first year of life.



## Introduction

Thinking about things that are not directly perceptually accessible requires memory. Although both infants (Bauer, 2007; Oakes & Bauer, 2007; Rovee-Collier, 1999) and adults (Squire, 2009; Tulving, 2002) can store durable memory representations over long periods of time, they also must have access to a form of memory that can create and manipulate representations rapidly and on the fly. Working

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memory, which allows for the temporary storage of information, has been shown to serve this role across the life span (Cowan, 1997; Oakes & Bauer, 2007). A hallmark of working memory is its highly limited capacity, whereby only a few items can be represented at any given time. However, adults, children, and even 14-month-old toddlers have been shown to mentally reorganize—or "chunk"—information in working memory, thereby increasing the total amount of remembered material. Here we asked whether this type of chunking of items is also available to younger preverbal infants whose working memory has not yet matured to adult-like capacity.

### *Working memory capacity limits during infancy*

From early in life, infants represent hidden objects in memory, an ability critical to learning about the world. Consider the everyday challenges infants face, such as watching a favorite toy become covered by a blanket and seeing one's mother disappear into another room. To lift the blanket and retrieve the hidden object or to crawl after a parent, infants must rely on representations stored in memory. Laboratory tasks have demonstrated that infants can represent such absent or occluded objects. For example, 5-month-olds who saw a doll hidden behind a screen and then saw another doll added behind the same screen looked longer when the screen was lifted to reveal unexpected outcomes of one or three dolls than at the expected outcome of two dolls (Wynn, 1992). Because the two dolls were never shown simultaneously during the hiding event, this looking preference suggests that infants maintained a representation of the first object in memory and then mentally updated it to reflect the addition of the second object (see also Feigenson, Carey, & Spelke, 2002; Koechlin, Dehaene, & Mehler, 1997; Simon, Hespos, & Rochat, 1995; Uller, Carey, Huntley-Fenner, & Klatt, 1999).

The representations that allow infants to remember a toy hidden under a blanket, or to represent the outcome when two dolls are serially hidden, need not reside in working memory. For example, these could be long-term representations with greater longevity and robustness. However, one piece of evidence suggesting that infants may rely on working memory in tasks like (Wynn, 1992) comes from the striking cases in which infants fail to remember. Across a variety of paradigms, adults have been shown to concurrently represent a maximum of only three or four visual items over brief durations (e.g., Alvarez & Cavanagh, 2004; Broadbent, 1975; Cowan, 2001; Luck & Vogel, 1997; Song & Jiang, 2006; Xu, 2002; Xu & Chun, 2006). This limit on the number of remembered items has been taken as a signature of visual short-term memory or working memory representations. A similar limit has emerged from tasks measuring the number of hidden objects infants can remember over durations ranging from less than a second to several seconds. In one series of studies, the memory capacity of 12- to 20-month-olds was measured by hiding varying numbers of objects in a box, allowing infants to retrieve either all or just a subset of the objects, and then asking whether infants continued searching the box for any remaining objects. When three or fewer objects were hidden and they had retrieved only a subset, infants successfully continued searching for the missing objects. However, when more than three objects were hidden, infants failed to continue searching (Barner, Thalwitz, Wood, Yang, & Carey, 2007; Feigenson & Carey, 2003, 2005; Feigenson & Halberda, 2004, 2008). These results suggest that infants can successfully represent one, two, or three hidden objects but fail to remember four or more objects.

A similar capacity limit was revealed when measuring infants' visual short-term memory (VSTM) for very briefly presented items using methods more similar to those used with adults (e.g., Luck & Vogel, 1997). In that experiment, 10- and 13-month-olds saw two flickering streams of colored squares. In the Changing Stream, one of the squares changed its color between each 500-ms flicker, while the other squares maintained their colors. In the Non-Changing Stream, all of the squares' colors stayed constant across flickers. Infants looked longer at the Changing Stream than at the Non-Changing Stream when the array contained one, two, three, or four squares, suggesting that they had maintained representations of the squares, compared these in memory, and noticed the color change. However, infants failed to look longer at the Changing Stream when the array contained six squares (Ross-Sheehy, Oakes, & Luck, 2003), suggesting that infants could not remember the features of this many items. This similarity in the capacity limits observed with 10- to 20-month-olds and with adults, spanning a range of methods, suggests that in some ways working memory capacity may be consistent