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What goes where? Eye tracking reveals spatial relational memory during infancy

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ABSTRACT

Episodic memory involves binding components of an event (who, what, when, and where) into a relational representation. The ability to encode information about the relative locations of objects (i.e., spatial relational memory) is a key component of episodic memory. Here we used eye tracking to test whether infants and toddlers learn about the spatial relations among objects. In Experiment 1, 9-, 18-, and 27-month olds were familiarized with an array of three objects. Following familiarization, they saw test arrays in which two of the objects had been replaced with novel ones (object switch condition) and arrays in which two of the objects had switched positions (location switch condition). Both 18- and 27-month olds looked significantly longer than would be predicted by chance at the objects that had switched spatial locations; however, 9-month olds did not. In Experiment 2, we showed that, given sufficient familiarization time, 9-month olds were also capable of detecting disruptions to the spatial relations among an array of objects. These results have important implications for our understanding of spatial relational memory development.

Introduction

Memories for events that we experience typically include details of who was there, what happened, when it happened, and where it happened. Compositionality is a key function of episodic memory

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(Henke, 2010); event memories are composed of individual components of an experience that are linked to form a coherent event representation. Episodic memories are composed of networks of relational representations (Cohen & Eichenbaum, 1993; Eichenbaum, Otto, & Cohen, 1992); relational networks allow event memories to be rapidly retrieved when a component cue is activated. Individual event networks are also connected to other events that share features, allowing us to make inferences about memories that are only indirectly related. Studies of lesioned animals (Eichenbaum, 2004), amnesic patients (Ryan, Althoff, Whitlow, & Cohen, 2000), and human brain activation (Konkel, Warren, Duff, & Tranel, 2008) have shown that the hippocampus is critically involved in episodic memory functions generally and memory for the relations among event components specifically.

Relational memory refers to the binding of associated event elements, including individual items (who/what) as well as spatial (where) and temporal (when) information. Spatial relational memory allows us to remember "what" happens "where." Remembering where you parked your car in the garage, or where your passport is in the filing cabinet, requires you to encode the position of the target object in relation to other objects in the environment. This kind of relational binding is essential for successful navigation and has been shown to depend on the hippocampus (Astur, Taylor, Mamelak, Philpott, & Sutherland, 2002; Banta Lavenex, Amaral, & Lavenex, 2006).

Research looking at episodic memory development in toddlers has shown that children as young as 3 years are able to encode the relative location of objects in the environment and use this information to guide search behavior. For example, Hayne and Imuta (2011) had children hide three toys in specific locations in different rooms in their house (e.g., Big Bird is hidden in the bedroom behind the curtain). Following a 5-min delay, children were asked to verbally recall the identity and location of the toys along with the order in which they were hidden. Children were also asked to search for each object, and behavioral recall was coded. The results showed that although 3-year olds recalled less information than 4-year olds when asked about where the toys were hidden, spatial relational memory did not differ between the two groups. Both 3- and 4-year olds were able to accurately find the toys when asked to search for them.

Spatial relational memory has also been studied in infants as young as 12 months using object search tasks. In these tasks, children watch the experimenter hide a toy and are encouraged to search for the toy after a delay (Bushnell, McKenzie, Lawrence, & Connell, 1995; Sluzenski, Newcombe, & Satlow, 2004). The accuracy of search behavior or the distance between the search position and hiding position (i.e., search error) is used as an index of memory. Children as young as 12 months can accurately search for a single object, particularly when its location is signaled by a distinctive cue; however, they have difficulty in using the relative location of two objects or cues to guide search behavior. For example, Bushnell et al. (1995) showed that 12-month olds were able to find a toy when it was hidden under a distinctive cushion, but not if it was hidden under a cushion that was in a particular location relative to a distinctive cushion. Similarly, Sluzenski et al. (2004) had children watch the experimenter repeatedly bury two toys that were always hidden in the same relative position to each other in a sandbox. Following a fixed training period, the experimenter hid the two toys out of sight of children, and then the location of one toy was revealed. Children were encouraged to search for the second toy using the relative location of the first one. Sluzenski and colleagues showed that 2- and 3-year olds were able to use spatial relations to accurately guide search behavior in this task; however, more than half of 18-month olds were unable to even complete the training.

The ability to use the relative position of several cues to guide search behavior improves late in the second year of life (Ribordy, Jabès, Lavenex, & Lavenex, 2013; Sluzenski et al., 2004) and continues to improve during early childhood (Schutte, Spencer, & Schöner, 2003). Using a paradigm in which children searched an arena of overturned cups for hidden rewards, Ribordy et al. (2013) showed that it was not until 43 months of age that children reliably found rewards when searching in a complex array of 18 possible search locations. When only 4 possible search locations were used, 18- to 23-month olds still failed to reliably locate the cup containing the reward. Although these data, along with those of Sluzenski et al. (2004), suggest that spatial relational memory might not be functional during infancy, it is possible that infants learn about the spatial relations among objects before they are able to use this information flexibly to guide successful search behavior. Research using novelty preference tasks to study spatial relational memory in animals may be useful in informing our understanding of human development in this area.