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Development of allocentric spatial memory abilities in children from 18 months to 5 years of age

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ABSTRACT

Episodic memories for autobiographical events that happen in unique spatiotemporal contexts are central to defining who we are. Yet, before 2 years of age, children are unable to form or store episodic memories for recall later in life, a phenomenon known as infantile amnesia. Here, we studied the development of allocentric spatial memory, a fundamental component of episodic memory, in two versions of a real-world memory task requiring 18 month- to 5-year-old children to search for rewards hidden beneath cups distributed in an open-field arena. Whereas children 25–42-months-old were not capable of discriminating three reward locations among 18 possible locations in absence of local cues marking these locations, children older than 43 months found the reward locations reliably. These results support previous findings suggesting that allocentric spatial memory, if present, is only rudimentary in children under 3.5 years of age. However, when tested with only one reward location among four possible locations, children 25–39-months-old found the reward reliably in absence of local cues, whereas 18–23-month-olds did not. Our findings thus show that the ability to form a basic allocentric representation of the environment is present by 2 years of age, and its emergence coincides temporally with the offset of infantile amnesia. However, the ability of children to distinguish and remember closely related spatial locations improves from 2 to 3.5 years of age, a developmental period marked by persistent deficits in long-term episodic

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memory known as childhood amnesia. These findings support the hypothesis that the differential maturation of distinct hippocampal circuits contributes to the emergence of specific memory processes during early childhood.

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1. Introduction

Episodic memories for autobiographical events that happen in unique spatiotemporal contexts are central to defining who we are. Yet, prior to about two years of age, children are unable to form or store episodic memories for recall later in life, a phenomenon known as infantile amnesia (Bachevalier, 1992; Bauer, 2007; Nadel & Zola-Morgan, 1984; Newcombe, Lloyd, & Ratliff, 2007). The three to five years that follow this period are characterized by fewer episodic memories than would be predicted based on a simple forgetting function alone, a phenomenon referred to as childhood amnesia (Bachevalier, 1992; Bauer, 2007; Nadel & Zola-Morgan, 1984; Newcombe et al., 2007). To date, the neurobiological bases for these phenomena have remained highly hypothetical (Bachevalier, 1992; Bauer, 2007; Nadel & Zola-Morgan, 1984; Newcombe et al., 2007). In contrast, research conducted over the last 30 years has established that multiple memory systems are subserved by different brain circuits in adult individuals (Squire, 1992; White & McDonald, 2002). In particular, declarative memory, which includes episodic memory and semantic memory (i.e., factual knowledge about the world), is dependent on the integrity and function of the hippocampal formation in adult humans (Milner, Squire, & Kandel, 1998; Morris, 2007), whereas non-declarative memories are not (Squire, 1992). Allocentric spatial memory, the memory for locations coded in a relational manner to the surrounding environment, is a fundamental component of episodic memory, the “where” component of the defining “what, where and when” of episodic memories (Nyberg et al., 1996; Tulving, 2002). Like semantic and episodic memory, allocentric spatial memory is also dependent on the integrity and function of the hippocampus in adult individuals (Banta Lavenex, Amaral, & Lavenex, 2006; Morris, Garrud, Rawlins, & O’Keefe, 1982; O’Keefe and Nadel, 1978; Olton, Walker, & Gage, 1978; Place et al., 2012; for a review of the theory of the general relational nature of the hippocampus, see Konkel & Cohen, 2009), whereas egocentric spatial memory, the memory for locations coded in relation to the body such as “on my left”, “on my right” or “in front of me”, is not (Banta Lavenex & Lavenex, 2009; Eichenbaum, Stewart, & Morris, 1990; Rogers & Kesner, 2006; Weniger & Irlle, 2006; Weniger, Ruhleder, Wolf, Lange, & Irlle, 2009). However, despite our ever-increasing comprehension of the role that the hippocampal formation serves in learning and memory in adult individuals, our understanding of how different memory systems develop and why different types of hippocampus-dependent memory emerge when they do in early childhood is much less complete (see Bauer, 2007; Newcombe et al., 2007 for reviews). Here, we studied the development of allocentric spatial memory, a fundamental component of episodic memory, in children from 18 months to five years of age in order to shed light on infantile and childhood amnesia and the development of hippocampus-dependent memory processes in children.

The ability of infants and toddlers to remember the location of an object in an egocentric frame of reference has been extensively studied, and performance has been shown to depend on a number of factors including the age of the child, the length of the delay between hiding and finding, and the amount of pre-training (which can bias the infant towards egocentric responding) the child receives (see Newcombe & Huttenlocher, 2000 for a review). In contrast, although the emergence and maturation of allocentric spatial memory abilities in children has also been extensively studied, the majority of studies have yielded disparate and seemingly conflicting results with respect to when spatial competence emerges and matures in children. An important exception, however, is one study by Newcombe and colleagues reporting that from 22 months of age children demonstrate the ability to use allocentric spatial information (Newcombe, Huttenlocher, Bullock Drummey, & Wiley, 1998). Children watched while a small plastic toy was buried in a sandbox. Half of the children were tested with access to distal visual cues in the room during hiding and retrieval, whereas the other half did not have access

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