Journal of Experimental Child Psychology 170 (2018) 1–29

Contents lists available at ScienceDirect

Journal of Experimental Child Psychology

journal homepage: www.elsevier.com/locate/jecp

Effects of two-dimensional versus three-dimensional landmark geometry and layout on young children's recall of locations from new viewpoints

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ARTICLE INFO

Article history:
Received 26 July 2017
Revised 12 December 2017

Keywords:
Allocentric
Virtual reality
2D versus 3D
In the middle
Spatial recall
Navigation

ABSTRACT

Spatial memory is an important aspect of adaptive behavior and experience, providing both content and context to the perceptions and memories that we form in everyday life. Young children's abilities in this realm shift from mainly egocentric (self-based) to include allocentric (world-based) codings at around 4 years of age. However, information about the cognitive mechanisms underlying acquisition of these new abilities is still lacking. We examined allocentric spatial recall in 4.5- to 8.5-year-olds, looking for continuity with navigation as previously studied in 2- to 4-year-olds and other species. We specifically predicted an advantage for three-dimensional landmarks over two-dimensional ones and for recalling targets "in the middle" versus elsewhere. However, we did not find compelling evidence for either of these effects, and indeed some analyses even support the opposite of each of these conclusions. There were also no significant interactions with age. These findings highlight the incompleteness of our overall theories of the development of spatial cognition in general and allocentric spatial recall in particular. They also suggest that allocentric spatial recall involves processes that have separate behavioral characteristics from other cognitive systems involved in navigation earlier in life and in other species.

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https://doi.org/10.1016/j.jecp.2017.12.009
0022-0965/

Introduction

Spatial memory is the metaphorical hook on which our everyday experiences hang; when having a complex interaction with another person, adapting to a new structure of potential rewards, or even having a simple percept of a new sight, sound, or smell, our perceptions come attached to locations that help us to contextualize and organize our experiences. Remembering locations reliably is also crucial for many everyday tasks on both small scales (e.g., finding keys on a cluttered desk) and large scales (e.g., giving directions to a friend). Schemes for remembering spatial locations can be parsed into *allocentric,* meaning world-based and relative to reference points that stay in the same place as the organism moves, and *egocentric,* meaning self-based and relative to the organism (Piaget & Inhelder, 1956). Allocentric memories are generally more useful because they remain stable even after an organism becomes disoriented or leaves an environment and returns later, although the two work together in many situations (e.g., Burgess, 2006). Allocentric spatial cognition is widely found to be more difficult (e.g., Burgess, Spiers, & Paleologou, 2004; King, Burgess, Hartley, Vargha-Khadem, & O'Keefe, 2002; Shelton & McNamara, 2001), to develop later in life (e.g., Acredolo, 1978; Negen, Heywood-Everett, Roome, & Nardini, 2017; Newcombe, Huttenlocher, Drummey, & Wiley, 1998; Piaget & Inhelder, 1956), and to depend on distinct neural substrates (see Bird & Burgess, 2008, for a review). Our recent studies using novel cognitive modeling analyses (Negen & Nardini, 2015; see also Nardini, Burgess, Breckenridge, & Atkinson, 2006) and virtual reality methods (Negen et al., 2017) have shown that allocentric spatial recall emerges shortly after a child's fourth birthday. In this article, our main goal was to better characterize those new allocentric spatial memory skills during middle childhood, specifically 4.5–8.5 years of age.

After reviewing effects seen in other spatial cognition tasks, we chose to focus on two potential factors that we expected to moderate performance: (a) an advantage for three-dimensional (3D) landmarks, where objects in the environment with some appreciable height might allow greater precision of allocentric recall than two-dimensional (2D) markings on the ground (e.g., Lee & Spelke, 2008), and (b) an advantage for targets "in the middle" of a landmark array, allowing greater precision for those targets versus ones that lay elsewhere (e.g., Ankowski, Thom, Sandhofer, & Blaisdell, 2012; Nardini, Thomas, Knowland, Braddick, & Atkinson, 2009). Because so little is known about what factors moderate performance in allocentric spatial memory in this age range, testing these two effects serves to address a major gap in the existing literature.

In the rest of this article, we use navigation as a point of comparison for our allocentric spatial recall task here. The difference in practice is just one of response modality; recall is defined as pointing to a remembered location, whereas navigation is defined as moving to a remembered location. Navigation tasks are much more common in the literature (e.g., Hermer & Spelke, 1994). However, recall tasks provide a stricter measure of children's allocentric reasoning, removing any egocentric methods of succeeding at the task (see Negen et al., 2017; cf. Stürzl, Cheung, Cheng, & Zeil, 2008). Using a recall task allows us to further characterize the cognition that it elicits for comparison with navigation. We hypothesized that two major performance effects in previous navigation studies would also be present in our spatial recall task because both are directed by the goals of understanding and working with spatial information. Alternatively, effects on performance might be very dissimilar because the act of navigating always gives an opportunity to gather and use egocentric information as the organism moves around (e.g., Stürzl et al., 2008), and a spatial recall task might be more related to scene perception or mental rotation skills. Supporting this, the ability to navigate to remembered locations after being disoriented emerges much earlier, from 1.5 to 2.0 years of age (Hermer & Spelke, 1994), versus 4 years of age for a task like ours (Negen et al., 2017). By using virtual reality to force participants to make responses without the aid of any egocentric information, we are both (a) characterizing allocentric spatial recall in greater detail and (b) seeing how similar the use of allocentric information by itself is to the various processes that support navigation, not just in terms of when they emerge but also in terms of what determines performance.