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Charting the development of cognitive mapping

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ABSTRACT

Developmental research beginning in the 1970s has suggested that children's ability to form cognitive maps reaches adult levels during early adolescence. However, this research has used a variety of testing procedures, often in real-world environments, which have been difficult to share widely across labs and to use to probe components of mapping, individual differences in success, and possible mechanisms of development and reasons for individual variation. In this study, we charted the development of cognitive mapping using a virtual navigation paradigm, Silcton, that allows for testing samples of substantial size in a uniform way and in which adults show marked individual differences in the formation of accurate route representations and/or in route integration. The current study tested children aged between 8 and 16 years. In terms of components of normative development, children's performance reached adult levels of proficiency at around age 12, but route representation progressed significantly more quickly than route integration. In terms of individual differences, by age 12 children could be grouped into the same three categories evident in adults: imprecise navigators (who form only imprecise ideas of routes), non-integrators (who represent routes more accurately but are imprecise in relating two routes), and integrators (who relate the two routes and, thus, form cognitive maps). Thus, individual differences likely originate during childhood. In terms of correlates, perspective-taking skills predicted navigation performance better than mental rotation skills, in accord with the view that perspective

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taking operates on extrinsic spatial representations, whereas mental rotation taps intrinsic spatial representations.

Introduction

Spatial navigation or wayfinding is necessary for everyday life. Successful navigation requires various cognitive skills, including encoding spatial relations from multiple sensory cues, maintaining these relations in memory, and transforming representations to orient and navigate in large-scale environments entered from various vantage points (Wolbers & Hegarty, 2010). For many investigators, the knowledge created using these skills constitutes a cognitive map, defined as an internal representation of large-scale environments that is integrated across separately encountered areas and that retains sufficient metric information to allow the generation of novel shortcuts and detours (O'Keefe & Nadel, 1978; Tolman, 1948). The cognitive map metaphor was extended to development in Siegel and White's (1975) proposal of a sequence from landmark to route to survey learning in both ontogeny and microgenesis and has inspired much research on spatial development.

Although some navigationally relevant skills emerge during infancy and the preschool period, important age-related change in navigational skills and representations of natural environments continue between 6 and 12 years of age (e.g., Acredolo, Pick, & Olsen, 1975; Allen, Kirasic, Siegel, & Herman, 1979; Heth, Cornell, & Alberts, 1997; Laurance, Learmonth, Nadel, & Jacobs, 2003; Overman, Pate, Moore, & Peuster, 1996). More recent research in natural environments has supported the conclusion that changes over middle childhood lead to mature spatial representations by the dawn of adolescence (Liben, Myers, Christensen, & Bower, 2013), and similar patterns emerge in research with smaller scale studies of memory for spatial location (Hund & Plumert, 2005), research on children's facility in integrating various sources of spatial information (Nardini, Burgess, Breckenridge, & Atkinson, 2006), studies of working memory for locations in navigable spaces (Belmonti, Cioni, & Berthoz, 2015), and spatial perspective taking (PT) in a route walking task (Vander Heyden, Huizinga, Raijmakers, & Jolles, 2017).

However, this body of developmental research explicitly or implicitly assumes that the mature end point of age-related change is the ability to construct survey representations or cognitive maps. This assumption is controversial. Some investigators have argued that cognitive maps are not necessary to explain spatial memory and wayfinding. For instance, navigation might be largely based on coding of movement, supplemented by constraints from a geometric module (Wang & Spelke, 2000, 2002, 2003), spatial memory might simply contain associative links (McNamara, 1986), or locally metric maps might be only roughly related to each other (Chrastil & Warren, 2014; Jacobs & Schenk, 2003; Kuipers, 2000). A recent approach to the debate concerning cognitive maps focuses on individual differences, proposing that people can sometimes form cognitive maps but that the abilities, strategies, and motivation required to do so are not always available or used (Weisberg & Newcombe, 2016). This formulation builds on findings of large and robust individual differences in navigation (Fields & Shelton, 2006; Hegarty, Montello, Richardson, Ishikawa, & Lovelace, 2006; Ishikawa & Montello, 2006; Weisberg & Newcombe, 2016).

Individual differences research requires large samples studied under controlled and comparable conditions. Gathering such data sets has been enabled by the development of virtual environments (VEs) to simulate real-world wayfinding tasks, to avoid logistical challenges in real-world environments, and to enable standardized methods across research groups (Maguire, Burgess, & O'Keefe, 1999; Weisberg, Schinazi, Newcombe, Shipley, & Epstein, 2014). Weisberg and colleagues (Weisberg & Newcombe, 2016; Weisberg et al., 2014) used a VE navigation task modeled on the route integration paradigm used in the natural world by Ishikawa and Montello (2006) and by Schinazi, Nardi, Newcombe, Shipley, and Epstein (2013). Participants demonstrated a substantial range of performance, suggesting that some adults form highly accurate representations of space, whereas others do not.