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Developmental time course of the acquisition of sequential egocentric and allocentric navigation strategies

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ABSTRACT

Navigation in a complex environment can rely on the use of different spatial strategies. We have focused on the employment of "allocentric" (i.e., encoding interrelationships among environmental cues, movements, and the location of the goal) and "sequential egocentric" (i.e., sequences of body turns associated with specific choice points) strategies during navigation. To investigate the developmental pattern of these two strategies in school-aged children, we used a virtual reality paradigm in which the spontaneous or imposed use of both strategies could be assessed. Our results showed an increase in spontaneous use of the allocentric strategy and also an increase in reliance on environmental landmarks with age. Although a majority of the children spontaneously used the sequential egocentric strategy, all age groups performed above chance when the allocentric strategy was imposed. Altogether, our findings suggest that young children are able to employ an allocentric strategy but that the nature of this allocentric strategy changes progressively in a complex cognitive representation between 5 and 10 years of age.

Introduction

Within spatial memory, a traditional distinction has been made between "allocentric" (world-centered) and "egocentric" (body-centered) representations (Arleo & Rondi-Reig, 2007; Burgess,

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2006, 2008). In rodents, allocentric (or place-learning) navigation is shown to depend on the hippocampus, whereas simple egocentric (stimulus–response like) navigation depends on the dorsal striatum (Morris, Garrud, Rawlins, & O'Keefe, 1982; O'Keefe and Nadel, 1978; Packard & Knowlton, 2002; White & McDonald, 2002). In more complex tasks, the hippocampus has been shown to be involved in not only allocentric (Aggleton & Brown, 1999; Burgess, Maguire, & O'Keefe, 2002; Byrne, Becker, & Burgess, 2007; O'Keefe and Nadel, 1978) but also in associative (Diana, Yonelinas, & Ranganath, 2007), sequential (Morris, 2001), or flexible (Eichenbaum, 2004; Rondi-Reig, Libbey, Eichenbaum, & Tonegawa, 2001) relational representations. Moreover, Rondi-Reig and colleagues (2006) showed that an additional "sequential egocentric" representation is dependent on the rodent hippocampus. A sequential egocentric strategy refers to the memorization of temporal relations between specific environmental choice points. The sequential egocentric strategy differs from a dead reckoning process in the sense that it does not allow online localization but rather allows the memory of temporal order of body turns associated with spatially distinct choice points.

The hippocampus in adult humans has likewise been associated with allocentric representations of location, allowing accurate navigation from new starting locations (Hartley, Trinkler, & Burgess, 2004) based on the configuration of environmental cues (Doeller & Burgess, 2008; Iaria, Petrides, Dagher, Pike, & Bohbot, 2003) or recognition of locations from a new viewpoint (Abrahams, Pickering, Polkey, & Morris, 1997; King, Burgess, Hartley, Vargha-Khadem, & O'Keefe, 2002; Lambrey et al., 2008). Navigation via a fixed route (Hartley et al., 2004; Iaria et al., 2003) or relative to a single landmark (Doeller & Burgess, 2008), consistent with simple egocentric representations, has been associated with the dorsal striatum. In line with the findings of Rondi-Reig and colleagues (2006), it recently has been shown that the hippocampus is involved in human navigation when the egocentric reference frame used involves temporal sequential ordering such as during the sequential egocentric strategy (Iglói, Doeller, Berthoz, Rondi-Reig, & Burgess, 2010).

In the current study, we were specifically interested in the developmental time course of the sequential egocentric and allocentric representations in children. Children of different ages were tested on a task in which they either were free to spontaneously use one strategy or the other or were "forced" to use the allocentric strategy. Early developmental work on spatial abilities suggested a shift from the use of egocentric representations to allocentric ones with age (Acredolo, 1978; Bremner & Bryant, 1977); in several training trials, 6- to 16-month-olds learned to locate an object on one side of their body midline and, after being turned around, were motivated to find back the object from the opposite side of the room or table. The 9- to 11-month-olds responded in an egocentric way, searching for the object on their body side where they had found it before, whereas the 16-month-olds searched for the object in the correct location in space. In addition, early empirical studies (Huttenlocher & Presson, 1973; Piaget & Inhelder, 1948) observed that allocentric representations develop well into the school years. Perspective-taking studies (e.g., the well-known "three mountain task" of Piaget & Inhelder, 1948) showed that until 9 or 10 years of age, children make a high rate of egocentric errors, suggesting their great reliance on this memory system. Similarly, it was shown that children younger than 5 years do not perform as well as older children and adults on keeping track of where they are in an eight-arm radial maze (Aadland, Beatty, & Maki, 1985; Foreman, Arber, & Savage, 1984). Also, experiments testing children in a Morris maze paradigm showed that place learning develops up to 7 to 10 years of age (Overman, Pate, Moore, & Peuster, 1996; Lehnung, Leplow, Friege, Herzog, & Ferstl, 1998; Leplow et al., 2003). However, allocentric representations appear to be present in younger children; accurate representations of locations within a testing room have been shown already at 36 months of age (Nardini, Burgess, Breckenridge, & Atkinson, 2006; Newcombe, Huttenlocher, Bullock Drummey, & Wiley, 1998), and children as young as 5 years are able to use a nonegocentric strategy if local landmarks are provided (Bullens et al., 2010; Lehnung et al., 1998). Therefore, converging evidence seems to indicate a gradual acquisition of the ability to use allocentric representations with age. It has been proposed that this developmental pattern is related to the delayed maturation of the hippocampus (Newcombe & Huttenlocher, 2003; Newcombe & Learmonth, 1999; Overman et al., 1996). Recently, it has been suggested that part of the difficulties young children have with complex goal-oriented tasks might