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Language and the Development of Spatial Reasoning

Human adult thought appears to transcend animal and infant capabilities greatly. In this chapter, we explore the possibility that language learning provides a path to mature cognition, focusing on the domain of spatial reasoning to probe questions about innate structure and conceptual change. We first summarize evidence that aspects of early spatial cognition rely on modular systems that exhibit characteristic limits in infants and animals. We then discuss how language could serve to overcome these limits.

Do human and animal minds consist of a collection of domain- and task-specific, encapsulated systems, or do they center on a single, central capacity for coordinating information and planning actions? In either case, are human cognitive capacities relatively constant over ontogeny, or do they change qualitatively with development and learning? Finally, are humans' cognitive systems shared by other animals, particularly nonhuman primates, or are certain systems unique to us?

This chapter has two faces. On the one hand, we argue that human and animal minds indeed depend on a collection of domain-specific, task-specific, and encapsulated cognitive systems: on a set of cognitive "modules" in Fodor's (1983) sense. These systems are largely constant over human development: they emerge in human infancy and undergo little qualitative change thereafter. Such core knowledge systems underlie many aspects of human cognition, from attentive tracking of objects (Carey & Xu, 2001) to estimation of numerosity (Dehaene, 1997) to representation of agency and intentionality (Johnson, 2000). Moreover, these systems are largely shared by humans and a variety of nonhuman animals, suggesting that they evolved before the differentiation of the human species. They link the

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sophisticated cognitive achievements of human adults to those of humbler creatures lacking language, culture, or education.

On the other hand, we argue that human and animal minds are endowed with domain-general, central systems that orchestrate the information delivered by core knowledge systems. One such system, associative learning, is common to human adults, infants, and nonhuman animals; it allows organisms to adapt their behavior to long-term regularities in the environment. A second system, however, is unique to human children and adults: the language faculty and the specific natural languages whose acquisition the language faculty supports. The latter system provides a medium that human children and adults use to combine information rapidly and flexibly, both within and across core domains.

Natural language has two properties that make it a good candidate mechanism for supporting interaction across conceptual domains. First, natural language has the flexibility to name concepts in any domain: "think" or "want" in theory of mind, "left" or "long" in the domain of space, "cup" or "on" in the domain of object mechanics. Second, natural language has the combinatorial structure to enable concepts from separate domains to be conjoined in phrases and sentences, for example, "I think he wants the cup that's to the left of the newspaper." Uniquely human combinatorial capacities that bind together information common to humans and other animals have previously been proposed to account for various aspects of cognition, including knowledge of the physical world (Carey & Spelke, 1994), knowledge of number (Spelke & Tsivkin, 2001), and theory of mind (de Villiers & de Villiers, 2003). Here we focus on the domain of spatial cognition, specifically the case of spatial reorientation (Cheng, 1986; Margules & Gallistel, 1988). We present evidence that language provides a mechanism by which children overcome limits to their core mechanisms for spatial representation. The hypothesis that language learning supports the development of spatial cognition has been spelled out previously (Spelke, 2003); the research presented here both tests this position and probes the mechanisms by which language might give rise to uniquely human representations of the spatial layout of the environment.

This chapter is divided into three parts. First, we review the literature on spatial reorientation in animals and in young children, arguing that spatial reorientation bears the hallmarks of core knowledge and of modularity. Second, we review studies of older children and adults, arguing that human spatial representations change qualitatively over development and show capacities not found in any other species. Third, we present two new experiments investigating the role of emerging spatial language in uniquely human navigation performance.

1 The Case of Spatial Reorientation

Many navigating animals can represent their own changing locations by integrating information about position, direction, and speed (e.g., Mittelstaedt & Mittelstaedt, 1980; Müller & Wehner, 1988). Because these computations are subject to cumulative errors, animals need to correct their sense of position and orientation by drawing on environmental representations in memory (Gallistel, 1990). The process of error correction, or *reorientation*, has been documented in a wide range of animals and serves to reveal what aspects of space animals and humans encode, remember, and use to regain their bearings.

1.1 *Comparative Studies on Reorientation*

In the earliest reorientation studies, food-deprived rats were shown the location of a food reward near a corner of a rectangular room with numerous visual and olfactory cues (Cheng, 1986; Margules & Gallistel, 1988). The rats were removed from the room, disoriented, and then returned to the room and allowed to search for the food. Rats searched equally at the target corner and at the corner located at a 180-degree rotation from the target, a location that had the same *geometric* relationship to the shape of the environment as the target location (fig. 6.1). Surprisingly, the rats did not use any of the nongeometric cues, such as the distinctive odors, brightnesses, scents, or textures in different regions of the environment, to distinguish between the two geometrically equivalent choices.

Importantly, rats failed to reorient by nongeometric information even though they detected the information, remembered it, and used it in other ways to guide their navigation. For example, Cheng and Gallistel noted that oriented rats readily learn to forage at a location marked by a panel of a distinctive brightness, pattern, or odor (e.g., Suzuki et al., 1980). They speculated that nongeometrically defined landmarks serve as direct cues to significant environmental locations, but not as cues to reorientation. In a preliminary test of this hypothesis, Cheng (1986) trained rats to forage at a position marked by a landmark. After disorientation in a rectangular room, the rats searched for food primarily at the correct, trained location. Cheng speculated that their search was guided by two independent processes: a reorientation process based exclusively on the shape of the room, and a landmark process based on a learned association between the nongeometric cue and the goal location.

Subsequent research has replicated Cheng's training effect in a variety of species: disoriented rhesus monkeys (Gouteux et al., 2001), rats (Dudchenko et al.,

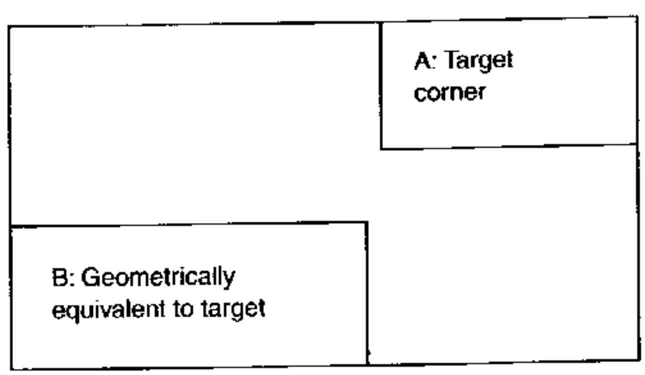

FIGURE 6.1 Schematic of the geometric effect in reorientation in a rectangular room. An object is hidden in the target corner (Corner A) while the subject watches. Following the disorientation procedure, there is no way to distinguish between Corner A and Corner B since they are located at rotationally symmetrical points (both are to the left of a short wall).