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Language, gesture, and judgment: Children's paths to abstract geometry

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ABSTRACT

As infants, children are sensitive to geometry when recognizing objects or navigating through rooms; however, explicit knowledge of geometry develops slowly and may be unstable even in adults. How can geometric concepts be both so accessible and so elusive? To examine how implicit and explicit geometric concepts develop, the current study assessed, in 132 children (3–8 years old) while they played a simple geometric judgment task, three distinctive channels: children's *choices* during the game as well as the *language* and *gestures* they used to justify and accompany their choices. Results showed that, for certain geometric properties, children chose the correct card even if they could not express with words (or gestures) why they had made this choice. Furthermore, other geometric concepts were expressed and supported by gestures prior to their articulation in either choices or speech. These findings reveal that gestures and behavioral choices may reflect implicit knowledge and serve as a foundation for the development of geometric reasoning. Altogether, our results suggest that language alone might not be enough for expressing and organizing

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geometric concepts and that children pursue multiple paths to overcome its limitations, a finding with potential implications for primary education in mathematics.

Introduction

Human infants and many nonhuman animals, from primates to insects, show sensitivity to geometry as they navigate through familiar environments or recognize objects by their shapes (Cheng & Newcombe, 2005; Spelke & Lee, 2012). In contrast, abstract geometric reasoning develops slowly in children and remains fragile even in educated adults, who perform no better than adults with no education on difficult tasks of triangle completion (Izard, Pica, Spelke, & Dehaene, 2011) and overestimate what they have learned from Socratic dialogues (Goldin, Pezzatti, Battro, & Sigman, 2011). Why is geometry both so accessible to action and perception and so opaque to thought? Here we attempted to shed light on this question through studies of young children's communication about geometry by examining three distinctive channels: their decisions (choices), their speech, and their gestures.

Geometry core systems allow human infants to present a high sensitivity to the geometry of their environment—the distance, angle, shape, and sense relations among extended surfaces (Lee, Sovrano, & Spelke, 2010; Samuelson & Smith, 2005; Smith, 2009). This sensitivity to geometry appears to build on at least two distinct early developing systems supporting navigation and object recognition (Landau & Lakusta, 2009; Lee & Spelke, 2010). Potentially, by harnessing these systems, children might also develop conceptions of truly abstract geometry (Dillon, Huang, & Spelke, 2013). To learn formal geometry, children must gain explicit access to the information captured by these early developing systems. But how? In other domains, including the natural number concepts at the center of the elementary school mathematics curriculum and the mental state concepts at the center of children's intuitive psychology and abilities to learn from others, the development of language and gestures guides children to the concepts that adults find to be most useful and relevant. Nevertheless, language might be not enough to develop knowledge of geometry because the key properties of even the simplest geometric concepts—such as *point, line, angle,* and *parallels*—are not captured by ordinary language (Landau & Jackendoff, 1993; Landau, 2017). For example, although lines in geometry are one-dimensional, perfectly straight, and infinitely extended, the ordinary word *line* refers to extended bodies (e.g., clothes line, fishing line) with none of these properties (e.g., thick line, wavy line, short line). No terms of ordinary speech, moreover, refer to key properties of lines such as parallelism and perpendicularity. How then do children and adults gain access to the basic concepts of Euclidean geometry?

The inaccessibility and signature limits of geometry-based navigation and object recognition systems can still be discerned in human adults and older children (Dehaene, Izard, Pica, & Spelke, 2006). Adults struggle to understand basic geometric properties of triangles and squares despite an otherwise successful mastery of mathematics in secondary school and college (Goldin et al., 2011). Older children become aware of the simplest properties of triangles, such as the relationships between the sizes of their angles, only during adolescence (Izard et al., 2011). Nevertheless, humans transcend these early systems of geometry in many contexts. Adults combine representations of distance, direction, relative length, and angle for a wide range of purposes, including explicit geometric reasoning (Dehaene et al., 2006; Izard et al., 2011). The current research begins to ask how adults come to accomplish this feat, and why it emerges so late in children, by analyzing how younger children reason about geometry in three distinctive channels: choices, speech, and gestures.

Gestures and words can convey different, and often contradictory, information

For more than three decades, researchers have investigated the role of co-speech gestures in the development of knowledge (Goldin-Meadow & Alibali, 2013; Goldin-Meadow, Wein, & Chang, 1992; LeBaron & Streeck, 2000; McNeill, 2005; Riseborough, 1982). When spoken languages are not