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Infants' perceptions of constraints on object motion as a function of object shape

Gelareh Jowkar-Baniani, Angelina Paolozza, Anishka Greene, Cho Kin Cheng, Mark A. Schmuckler *

University of Toronto Scarborough, Canada

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ABSTRACT

Three studies examined young infants' ability to distinguish between expected and unexpected motion of objects based on their shape. Using a preferential-looking paradigm, 8- and 12-month-old infants' looking time towards expected and unexpected motion displays of familiar, everyday objects (e.g., balls and cubes) was examined. Experiment 1 demonstrated that two factors drive infants' preferential fixations of object motion displays. Both 8- and 12-month-olds displayed a tendency to look at rotating information over non-rotating, stationary visual information. In contrast, only 12-month-olds showed a tendency to look at object motions that were inconsistent or "unexpected" based on shape. After controlling for the preference for more complex (rolling) by adding rolling motion to both displays (Experiment 2), 12-month-olds' ability to distinguish between expected and unexpected motion displays was facilitated. Experiment 3 provided a control by demonstrating that the preference for the unexpected object motion was not due to any other motion properties of the objects. Overall, these results indicate that 12-month-old infants have the ability to recognize the role that object shape plays in constraining object motion, which has important theoretical implications for the development of object perception.

1. Introduction

Infants' perceptions of objects is arguably one of the most thoroughly studied questions in the history of research in developmental psychology (see Johnson, 2010, 2011, 2013; Slater et al., 2010, for reviews). As aptly described by Johnson (2013, p. 371), "...(o)bject perception is the *raison d'être* of the visual system." The role of object motion in driving object perception is a particularly important, and compelling property that has been examined by a wide number of researchers in a wide array of contexts. Object motion provides critical information for the perception of three-dimensional object shape and structure (Arterberry, 1992; Arterberry, Craton, & Yonas, 1993; Arterberry & Yonas, 1988, 2000; Hirshkowitz & Wilcox, 2013; Kellman, 1984; Kellman & Short, 1987; Owsley, 1983; Schmuckler & Proffitt, 1994; Soska & Johnson, 2008, 2013; Wallach & O'Connell, 1953; Yonas, Arterberry, & Granrud, 1987), the three-dimensional layout of objects and surfaces (Johnson, 2000; Johnson, Davidow, Hall-Haro, & Frank, 2008; Johnson & Mason, 2002), and the three-dimensional completion of partly-occluded objects (Johnson, 2004; Johnson & Aslin, 1995, 1996; Kellman & Spelke, 1983; Mareschal & Johnson, 2002; Soska & Johnson, 2013). Object motion is similarly fundamental in the understanding of complex object properties such as animacy (Di Giorgio, Lunghi, Simion, & Vallortigara, 2016; Gelman, 1990; Mandler, 1992, 2003; Markson & Spelke, 2006; Poulin-Dubois, Crivello, & Wright, 2015; Rakison & Poulin-Dubois, 2001; Träuble & Pauen, 2011; Träuble, Pauen, & Poulin-Dubois, 2014). Clearly, object motion is one of the richest sources of information regarding innumerable object properties.

Motion is also critical for providing information regarding fundamental constraints on object properties and behavior in the environment, which in turn provides insight into foundational aspects of infants' knowledge and understanding of the world. Spelke and colleagues, in their theorizing on and investigations of infants' "core knowledge" (Dillon & Spelke, 2015; Spelke, Breinlinger, Macomber, & Jacobson, 1992; Spelke & Kinzler, 2007; Spelke, Lee, & Izard, 2010; Spelke, Phillips, & Woodward, 1995; Spelke & Van de Walle, 1993) provide one of the most intriguing, and elegantly articulated, examples of the consequence of the perception of object motion. Spelke et al. (1992), for instance, found that 4-month-old infants understood basic object constraints such as solidity (solid objects do not pass through other solid objects) and continuity (objects continue to move on a given path unless obstructed in some fashion), but failed to understand effects of gravity (objects will fall unless supported by other objects or surfaces) and inertia (a free falling object will continue to fall towards

* Corresponding author at: Department of Psychology, University of Toronto Scarborough, 1265 Military Trail, Scarborough, ON M1C 1A4, Canada.
E-mail address: marksch@utsc.utoronto.ca (M.A. Schmuckler).

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a support surface). According to Kim and Spelke (1992), it is not until 7 months that infants began to understand such properties, with full developmental understanding of these properties occurring between 7 months and two years of age (Kim & Spelke, 1999). Such findings demonstrate that although young infants understand basic constraints about the physical properties of objects (i.e., solidity, continuity), their understanding of the reasons underlying the behavior of objects and object movements (i.e., inertia, gravity) is a more advanced, later developmental achievement.

One characteristic common to much of this work is that the relation between object motion and understanding has been primarily unidirectional, with object motion providing the vehicle for insight into a host of foundational object and world knowledge (e.g., Mandler, 1992, 2003, 2008a, 2008b, 2010, 2012). Interestingly, little work (with a handful of notable exceptions, discussed momentarily) has considered the bidirectional implications of this relation. In this case, not only does object motion illuminate critical object properties, but basic object properties can also highlight, and potentially constrain, fundamental aspects of object motion. Probably the best known example of this type of relation is seen in the perception of biological motion based on point-light visual information (Cutting, 1978, 1981, 1986; Cutting, Moore, & Morrison, 1988; Johansson, 1973; Kozlowski & Cutting, 1977; Pavlova, Krägeloh-Mann, Birbaumer, & Sokolov, 2002; Pavlova & Sokolov, 2000; Troje, 2002, 2013; Westhoff & Troje, 2007). Stemming from the classic work by Johansson (1973), point-light biological motion displays are created by attaching spots of light and/or reflective markers to the major joints of the body. Despite their relative paucity of visual information, compared to viewing these same movements under normal illumination, such displays are easily recognized by adult observers as to the behaviors undertaken by actors. Beginning with work by Fox and McDaniel (1982) researchers have found that infants are similarly responsive to biological motion information. Within the first few months of life infants can discriminate human point-light displays from nonhuman (Bertenthal, Proffitt, & Kramer, 1987), are sensitive to the orientation of biological movement (Booth, Pinto, & Bertenthal, 2002), and so on. This research is significant in that it provides indirect evidence that such structure can indeed constrain the perception of object motion.

Of most direct relevance, Baker, Pettrigrew, and Poulin-Dubois (2014) investigated 10- to 20-month-old infants' expectations for motion paths as a function of object animacy. Building from previous research examining infants' expectations for animate actions to be extended more to animals than vehicles (Poulin-Dubois, Frenkiel-Fishman, Nayer, & Johnson, 2006), this work found that infants in this age range associated non-linear paths of motion with animate objects (animals) and linear paths of motion with inanimate moving (vehicles) and stationary (furniture) objects. Thus, infants do generate expectations for the types of motion that objects will display, with such expectations constrained by infants' conceptual understanding of the motion cues involved with animacy (Mandler, 1992, 2000, 2010, 2012).

Accordingly, there is evidence to suggest that basic object properties might influence ones' expectations for object movement. The goal of the current series of experiments was to examine this question more directly, within the context of infants' expectations for object movement based on physical shape.

2. Experiment 1: The role of object shape in expectations of object motion

The principal goal of this first experiment was to examine whether an object's shape would influence infants' expectations for the type of motion typically produced by this object. As an example, objects that are round, such as balls, move with a characteristic motion – they roll. Given its lack of flat surfaces, a significantly more non-characteristic motion for such an object would be for it to slide. In this case, the physical shape of the object drives expectations for the type of motion that should be produced by the object. By way of contrast, a differently structured object, such as a cube, because of its edges, corners, and flat surfaces, is more likely to move in a sliding fashion than a rolling fashion. Accordingly, the physical structure of a cube drives different, and opposite, expectations for object motion.

Expectations for the motion of these two objects, a ball versus a cube, were examined using the violation-of-expectation preferential looking paradigm (Baillargeon, Spelke, & Wasserman, 1985; Spelke et al., 1992). Based on previous findings, two target ages were identified – 8- and 12-month-old infants. Eight months is of interest given the literature suggesting that infants between 5 and 7 months become sensitive to the impact of physical structure on perceived motion in biological displays (e.g., Bertenthal, Proffitt, & Cutting, 1984; Bertenthal et al., 1987; Pinto, Bertenthal, & Booth, 1996). In contrast, research on infants' perceptions of complex object constraints such as gravity and inertia (Kim & Spelke, 1992, 1999; Spelke et al., 1992) indicate that such knowledge is not available until later in development, between 10 and 16 months (Kanass, Oakes, & Wiese, 1999). Based on these findings, if infants are sensitive to the impact of object shape on object movement we would predict that by 12 months infants will preferentially fixate unexpected object movements (a sliding ball and a rolling cube) over expected movements (a rolling ball and a sliding cube). Predictions for 8-month-olds are more variable. If 8-month-olds are generally sensitive to constraints on object movement imposed by shape, they should preferentially fixate unexpected displays. Alternatively, if an understanding of how object shape constrains object movement aligns with knowledge of complex object properties such as gravity and inertia, 8-month-olds will not have strong expectations for object movement based on shape. Instead, looking may be driven by other motion characteristics of the objects.

2.1. Methods

2.1.1. Participants

Sixteen 8-month-olds (M = 7.74 months, SD = 0.35 months) and sixteen 12-month-olds (M = 11.92 months, SD = 0.39 months) participated in this study. Ten additional 8-month-olds and one 12-month-old also participated but their data were excluded due to fussiness (N = 3) and technical errors (N = 8). The names of the participants were obtained from a database maintained at the Laboratory for Infant Studies at the University of Toronto Scarborough and parents were contacted by telephone. All participants were recruited from the demographically diverse Greater Toronto area and received a certificate and a toy for their participation.

2.1.2. Stimuli

Using the animation program 3DS Max, four video displays, shown schematically in Fig. 1, were created for this experiment. Two of the displays involved a colorful checkered ball with a diameter of 6.5 cm rolling (Fig. 1a) or sliding (Fig. 1b) across a flat surface and the other two showed a similarly patterned cube with a width of 6.5 cm sliding (Fig. 1c) or rolling (Fig. 1d) across a flat surface. Because both stimuli had comparable diameters, the visual angle for both the ball and cube was $5.7° \times 5.7°$. Rolling is considered the typical movement of a ball (expected event), whereas sliding is an atypical motion (unexpected event). For the cube, the motion patterns were reversed; sliding is considered the typical movement (expected event) whereas rolling is atypical