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Multiple visual quantitative cues enhance discrimination of dynamic stimuli during infancy

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ABSTRACT

Infants possess basic capabilities to assess various quantitative properties such as number, size, and time. Preverbal discriminations are approximate, however, and are similarly limited across these dimensions. Here, we present the first evidence that multiple sources of quantitative unisensory information about dynamic stimuli—namely, simultaneous visual cues to changes in both number and surface area—may accelerate 6-month-olds' quantitative competence. Using a habituation–dishabituation paradigm, results from Experiment 1 demonstrate that, when provided with such visual cues to multiple quantitative properties that occur in the same direction, infants make more precise discriminations than has been shown when they receive information about either cue alone. Moreover, Experiment 2 demonstrates that infants' discrimination also benefits from simultaneous visual cues to quantitative changes that occur in opposite directions. Finally, Experiment 3 demonstrates that these findings are not driven by infants' ability to discriminate a 2:3 ratio change in surface area of a dynamic stimulus alone. Thus, we hypothesize that enhanced quantitative discrimination occurs because simultaneous visual quantitative changes may be more salient than single-source information, which could better recruit attention and result in more precise learning and remembering.

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Introduction

Even before they acquire language, infants are capable of perceiving various quantitative dimensions such as time, size, and number (e.g., Brannon, Lutz, & Cordes, 2006; Jordan, Suanda, & Brannon, 2008; Lipton & Spelke, 2003; Wood & Spelke, 2005; Xu, 2003; Xu & Spelke, 2000; Xu, Spelke, & Goddard, 2005). This ability is approximate in that it follows predictions made by Weber's law; that is, infants' ability to distinguish between two magnitudes is a function of the ratio between the competing magnitudes (e.g., Bijeljac-Babic, Bertioncini, & Mehler, 1993; Brannon, Abbot, & Lutz, 2004; Gao, Levine, & Huttenlocher, 2000; Izard, Sann, Spelke, & Streri, 2009; Xu & Spelke, 2000). For example, 6-month-olds successfully distinguish a 1:2 surface area change of a static visual object but fail to notice a 2:3 surface area change (Brannon et al., 2006). Similarly, when tested with visual stimuli, 6-month-olds require a 1:2 ratio for successful discrimination of large numerical sets but fail to discriminate a 2:3 ratio change (e.g., Wood & Spelke, 2005; Xu, 2003; Xu & Spelke, 2000; Xu et al., 2005). In addition, 6-month-olds fail to differentiate temporal intervals that differ by a 2:3 ratio but succeed on temporal intervals of a 1:2 contrast (Brannon, Suanda, & Libertus, 2007). This pattern suggests that discrimination abilities of infants show similar perceptual limits across various dimensions of visual quantity.

However, infants' discrimination abilities are not fixed. When given multiple simultaneous cues to changes in quantitative properties, infants' quantitative abilities are enhanced (e.g., Jordan et al., 2008; Suanda, Tompson, & Brannon, 2008). These effects may be driven by intrinsic aspects of humans' perceptual development such as the propensity for infants to explore their environments, thereby facilitating exposure to such cues (Gibson, 1982, 1984). Much evidence suggests that humans are born with the ability to perceive various multimodal properties such as stimulus intensity (Lewkowicz & Turkewitz, 1981), tempo (Gardner, Lewkowicz, Rose, & Karmel, 1986), number (Izard et al., 2009), and others (see Lewkowicz, 2000, for a review). Human infants may use sensations from multiple cues in particular—such as those from multiple sensory modalities—to discriminate these multimodal properties of objects and events in their environment (Lewkowicz, 2000). Because temporally and spatially synchronous cues provide such simultaneous multimodal information about stimuli in the environment, infants may preferentially attend to them over single-source cues (Jordan et al., 2008; Lewkowicz, 2000; Suanda et al., 2008). Thus, when multiple synchronous cues to a quantitative property occur within an infant's perceptual environment, not only will the infant preferentially attend to it over a property not specified by multiple cues, but also the greater information provided by the multiple cues—often from multiple modalities—allows for more accurate encoding of the property, which in turn facilitates finer perceptual discriminations.

The intersensory redundancy hypothesis (see Bahrick & Lickliter, 2000, for a review) states that synchronous and redundant stimulation from multiple sensory modalities efficiently recruits infants' attention by providing overlapping sensory information about a single stimulus property, thereby causing the redundantly specified property to become perceptual "foreground" while other sensory stimulation remains "background." Enhancing effects of intersensory redundancy on infants' and children's discrimination abilities are well documented (Bahrick, Flom, & Lickliter, 2002; Bahrick & Lickliter, 2000; Jordan & Baker, 2011; Jordan et al., 2008; Kraebel, 2012). For example, using a habituation/dishabituation paradigm, Bahrick et al. (2002) demonstrated that 3-month-olds are better able to discriminate variations in tempo following multimodal (i.e., audiovisual) stimulation as opposed to unimodal stimulation. Similarly, simultaneous audiovisual sensory input enhances 6-month-olds' ability to discriminate stimuli on the basis of number (Jordan et al., 2008). According to the intersensory redundancy hypothesis, temporal and spatial congruity preferentially fosters perceptual differentiation, learning, and memory for redundant multimodal properties compared with unisensory, modality-specific stimulus properties (Bahrick & Lickliter, 2000).

More rarely, studies have demonstrated enhanced quantitative abilities in response to simultaneous cues that occur within the same sensory modality. For example, 9-month-olds are capable of detecting changes in ordinal direction of a sequence of arrays when multiple visual cues covary but fail when only a single cue varies (Suanda et al., 2008). Similarly, 7-month-olds successfully