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Brief article

Intersensory redundancy accelerates preverbal numerical competence

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Abstract

Intersensory redundancy can facilitate animal and human behavior in areas as diverse as rhythm discrimination, signal detection, orienting responses, maternal call learning, and associative learning. In the realm of numerical development, infants show similar sensitivity to numerical differences in both the visual and auditory modalities. Using a habituation–dishabituation paradigm, we ask here, whether providing redundant, multisensory numerical information allows six-month-old infants to make more precise numerical discriminations. Results indicate that perceptually redundant information improved preverbal numerical precision to a level of discrimination previously thought attainable only after additional months of development. Multimodal stimuli may thus boost abstract cognitive abilities such as numerical competence.

Keywords: Numerical cognition; Multisensory processes; Cognitive development; Intersensory redundancy; Infancy

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1. Introduction

Much evidence supports the claim that preverbal infants have rudimentary numerical competence (e.g., Brannon, 2002; Brannon, Abbott, & Lutz, 2004; Jordan & Brannon, 2006; Lipton & Spelke, 2003, 2004; Xu & Arriaga, 2007; Xu & Spelke, 2000; Xu, Spelke, & Goddard, 2005). For instance, seven-month-old infants can match the number of faces they see to the number of voices they hear, thus equating numerical value across sensory modalities, and six-month-old infants can discriminate between large numerical values (e.g., Jordan & Brannon, 2006; Xu & Spelke, 2000). The ability to discriminate large numerical values in infancy, however, is dependent on the ratio between the values. When six-month-old infants are habituated to visual arrays that contain 8 or 16 dots and then tested with new, alternating dot arrays of both numerosities, they look longer at the test displays with the novel numerosity (Xu & Spelke, 2000). In contrast, infants of this same age fail to discriminate 8 vs. 12 dots, suggesting that at six months, infants require a 1:2 ratio to make numerical discriminations between visual arrays (see also Xu, 2003; Xu et al., 2005).

Lipton and Spelke (2003) showed the same ratio dependence for numerical discrimination of auditory stimuli in infancy. Specifically, in a preferential head-orienting paradigm, six-month-old infants discriminated 8 vs. 16 tones but failed to discriminate 8 vs. 12 tones, suggesting that a 1:2 ratio is also necessary for auditory number discrimination at six months of age. Finally, six-month-old infants likewise require a 1:2 ratio to successfully discriminate the number of visual events (in the form of puppet jumps; Wood & Spelke, 2005). This precision with which infants make numerical discriminations increases with age such that by nine months, infants can discriminate 8 dots from 12 dots, 4 puppet jumps from 6 puppet jumps, and 8 tones from 12 tones (Lipton & Spelke, 2003; Wood & Spelke, 2005; Xu & Spelke, 2000). Collectively, such data suggest that (1) Regardless of the sensory modality in which stimuli are experienced, at six months of age infants require a 1:2 ratio for successful numerical discrimination; and (2) Between six and nine months of age, the threshold of discrimination increases from a 1:2 ratio to a 2:3 ratio.

Here, we challenge this accepted view in the infant numerical literature by asking whether the precision with which infants make numerical discriminations is enhanced if they are provided with synchronous, redundant information about number through multiple sensory modalities. When given information that is redundant across multiple senses, non-human animals and humans tested on a wide variety of non-numerical dimensions have been shown to improve in accuracy and/or reaction time, relative to performance with unisensory stimuli (e.g., Bahrick & Lickliter, 2000; Gogate & Bahrick, 1998; Lewkowicz & Kraebel, 2004; Lickliter, Bahrick, & Honeycutt, 2002; Lovelace, Stein, & Wallace, 2003; Mellon, Kraemer, & Spear, 1991; Meredith & Stein, 1983). For example, multimodal cues occurring together in time and space enhance responses of multisensory neurons in the superior colliculus of cats to a level above the responses evoked by unisensory cues; multisensory cues also produce behaviorally evident increases in cats' effectiveness at detecting, orienting towards, and approaching the cue as compared with responses to unimodal sensory