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Infants perceive two-dimensional shape from horizontal disparity

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ABSTRACT

Previous studies observed that responsiveness to horizontal disparity as such emerges at approximately 2 months of age. Moreover, 3- to 4-month-old infants utilize stereoscopic information to perceive object variations in depth. The present study investigated infants' ability to respond to crossed horizontal disparity information that defines two-dimensional shape. Infants 4 and 5 months of age were habituated to either a cross or the outline of a square. During the posthabituation period, they were presented with both shapes. The stimuli were dynamic random dot stereograms shown on an autostereoscopic monitor. The participants 5 but not 4 months of age displayed significant novelty preferences for the unfamiliar shape during the posthabituation period. Five-month-old infants are hence sensitive to horizontal disparity information that specifies shape.

1. Introduction

Research on the onset and development of depth and shape perception in the first year of life has mainly concentrated on pictorial and kinetic cues (for reviews, see Arterberry & Kellman, 2016; Norcia & Gerhard, 2015). The existing studies on infant stereoscopic vision deal primarily with the development of responsiveness to binocular disparity (for a review, see Braddick, 1996). The distal world around us projects slightly different images on the two retinae, termed binocular disparities. Stereopsis is the ability of our visual system to transfer binocular disparities into information about distance and two- and three-dimensional object shape (for a review, see Cumming & DeAngelis, 2001).

Infant responsiveness to binocular disparity information has been investigated using either measurement of visual evoked potentials (VEPs) or measurement of gaze behavior. A special type of stimuli employed in both paradigms are random dot stereograms (RDS). By horizontally shifting a specific region within the random dot elements of one of the half-images of a RDS, a stereoscopic shape can be generated. According to VEP studies, neurophysiological responses to dynamic RDS (DRDS) can be observed after approximately 3 months of age (e.g., Birch & Petrig, 1996; Skarf, Eizenman, Katz, Bachynski, & Klein, 1993). This age of onset has also been found in looking studies with RDS (e.g., Brown, Lindsey, Satgunam, & Miracle, 2007; Fox, Aslin, Shea, & Dumais, 1980). Other investigations, however, suggest that infants respond to horizontal disparity information in RDS even from approximately 8 to 9 weeks of age onward (e.g., Brown & Miracle, 2003; Wattam-Bell, 2003). From about 3 months of age onward, infants are sensitive to uncrossed horizontal disparity (e.g., Kavšek & Braun, 2016).

These studies indicate that infants are sensitive to variations in horizontal disparity. They do not inevitably imply that infants are additionally able to extract stereoscopically specified depth and shape (Braddick, 1996). Gordon and Yonas (1976) and Yonas, Oberg, and Norcia (1978) observed reaching responses to distance variations provided by binocular information which was generated by a stereoscopic shadow casting device. The results of these studies suggest that 5-month-old infants are sensitive to binocular depth

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information. For example, Yonas, Oberg, and Norcia, (1978) created a stereoscopic display which evoked the impression of an approaching object on a collision course. Infants 20 but not 14 weeks of age reached for the object. Moreover, they displayed defensive blinks and head movements. In another approach, infant reaching under both monocular and binocular viewing conditions was measured. Binocular vision is known to provide the visual system with more accurate information about object location than monocular vision. Several studies created displays which manipulated pictorial depth cues in such a way that two or more objects appeared to be situated at different distances from the observer when viewed monocularly. This effect was eliminated when the displays were viewed binocularly: under binocular viewing conditions, it could be discerned that the objects were in fact equidistant (e.g., Arterberry, 2008; Yonas, Elieff, & Arterberry, 2002; for a review see Kavšek, Granrud, & Yonas, 2009). These studies found that 5- and 7-month-old infants exhibit different reaching preferences under monocular versus binocular viewing conditions. Under monocular viewing conditions, infants reach preferentially for the object that is specified as being nearer by pictorial depth cues. In contrast, there is no clear reaching preference under binocular viewing conditions. Reaching/catching under both monocular and binocular viewing was also analysed by Granrud (1986); van Hof, van der Kamp, and Savelsbergh, (2006), and Ekberg et al. (2013). In these studies, infant reaching/catching toward varying object positions was assessed. For instance, van Hof et al. (2006) observed more accurate catches for an approaching object even in infants 3 to 4 months of age under binocular viewing.

Using a habituation-dishabituation design, Yonas, Arterberry, and Granrud, (1987) examined the ability to react to shape from stereoscopic information in infants 4 months of age. The participants were divided into a disparity-sensitive and a disparity-insensitive group. The infants were then habituated to either a flat or a three-dimensional object. Both object shapes were specified by kinetic information. Afterwards, using the stereoscopic shadow casting technique, the infants were presented with stereograms displaying both the flat and the three-dimensional object. Only the disparity-sensitive participants showed significant posthabituation responses to the novel shape. Yonas et al. (1987) concluded that 4-month-old infants who are sensitive to disparity are able to extract shape from both motion and stereoscopic information.

In the shadow casting method, two slightly different shadows/images of an object are casted onto a rear projection screen using two point-source lamps. Polarizing filters are placed in front of the two lamps and the participant wears glasses with corresponding filters. Such, two separate views of the object, that is a dichoptic situation, is created. Yonas et al. (1987) point out that shadow casters provide the observer with both horizontal disparity and convergence angle information about object shape. Indeed, according to Aslin and Dumais (1980), in the shadow casting technique, the screen lacks contour information to adjust convergence to the screen plane. As a consequence, infant observers might simply bifoveally fixate the two half-images projected onto the screen rather than the screen plane. This visual behavior does not deliver horizontal disparity information. Instead, the infants might use binocular convergence angle as a 3D cue. To avoid this problem, Yonas et al. (1987) propose to employ RDS because they isolate horizontal disparity from convergence information. The present study therefore used DRDS. Moreover, the relative shift of the shapes embedded in the half-images of DRDS cannot be detected by alternate eye closure. As a consequence, this specific monocular cue can also not be the basis for distinguishing different shapes in DRDS.

To our knowledge, all earlier studies on infant stereoscopic vision used eyeglasses with either red-green filters (e.g., Brown & Miracle, 2003; Wattam-Bell, 2009), shutter lenses (e.g., Skarf et al., 1993), or polarized lenses (e.g., Yonas et al., 1987) to separate the half-images sent to the infants' eyes. Unfortunately, 3D glasses might exert a disturbing effect on infants' looking behavior (e.g., Broadbent & Westall, 1990). We circumvented this disadvantage by presenting DRDS on an autostereoscopic monitor.

To summarize, prior studies have shown that infants are sensitive to horizontal disparity information by 2 months of age. Catching studies found infants aged 3 to 4 months detect depth from horizontal disparity. Moreover, the findings obtained by Yonas et al. (1987) suggest that infants might be able to extract three-dimensional shape from stereoscopic information by 4 months of age. The current habituation-dishabituation study explored whether 4- and 5-month-old infants are sensitive to stereo information that specifies flat shape. We first tested 5-month-old infants. After we had found that infants of this age obviously succeeded in responding to the experimental shapes, we additionally tested 4-month-old infants. The participants were habituated to either a cross or the outline of a square. During the posthabituation period, they were tested with both shapes. It was hypothesized that the infants would dishabituate to the unfamiliar shape, the shape not shown during habituation, if they were able to detect and to distinguish the shapes. Both shapes were embedded in DRDS (see Fig. 1).

2. Experiment

2.1. Method

2.1.1. Participants

The overall sample consisted of 32 full-term, healthy infants 4 months of age (16 girls; mean age = 124 days, range = 118–130 days) and 32 infants 5 months of age (16 girls, mean age = 151 days, range = 145–160 days). Twenty-five additional infants 4 and 20 infants 5 months of age could not be included in the final sample because the infant did not reach the habituation criterion (4-month-olds: $n = 1$; 5-month-olds: $n = 2$), did not attend to the experimental stereograms because of crying, being too distracted, or being too restless (4-month-olds: $n = 14$; 5-month-olds: $n = 12$), due to experimenter error or technical problems (4-months-olds: $n = 3$; 5-month-olds: $n = 6$), or due to looking at either the left or the right dishabituation pattern in more than 90% of the available looking time (4-month-olds: $n = 7$) (Haaf & Diehl, 1976).

The infants were recruited by letter and follow-up telephone calls. The names of the infants were obtained from birth records provided by the municipal authorities of the City of Bonn (Germany). The parents received 5 Euros for participation. They gave informed consent before testing was commenced. The study was approved by the ethics committee of the Department of Psychology