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Infants' discrimination of crossed and uncrossed horizontal disparity

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Abstract In a series of preferential-looking experiments, infants 5 to 6 months of age were tested for their responsiveness to crossed and uncrossed horizontal disparity. In Experiments 1 and 2, infants were presented with dynamic random dot stereograms displaying a square target defined by either a 0.5° crossed or a 0.5° uncrossed horizontal disparity and a square control target defined by a 0.5° vertical disparity. In Experiment 3, infants were presented with the crossed and the uncrossed horizontal disparity targets used in Experiments 1 and 2. According to the results, the participants looked more often at the crossed (Experiment 1), as well as the uncrossed (Experiment 2), horizontal disparity targets than at the vertical disparity target. These results suggest that the infants were sensitive to both crossed and uncrossed horizontal disparity information. Moreover, the participants exhibited a natural visual preference for the crossed over the uncrossed horizontal disparity (Experiment 3). Since prior research established natural looking and reaching preferences for the (apparently) nearer of two objects, this finding is consistent with the hypothesis that the infants were able to extract the depth relations specified by crossed (near) and uncrossed (far) horizontal disparity.

Keywords Infant vision · Perceptual development · Stereoscopic vision · Binocular vision · Horizontal disparity

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Introduction

During the last decades, infants' sensitivity to depth has been extensively explored. Research has shown that sensitivity to kinematic and pictorial depth cues emerges during the first months of life (for a review, see Kellman & Arterberry, 2006). Studies on the onset and development of stereopsis in infancy has largely concentrated on sensitivity to horizontal disparity and on binocular rivalry (for reviews, see Birch, 1993; Braddick, 1996). These studies suggest that stereoscopic functioning operates from approximately 2 to 5 months of age onward.

Infant stereopsis: Visual evoked potential studies

Infant stereopsis has been investigated using physiological and behavioral/looking methods. Birch and Petrig (1996) and Skarf, Eizenman, Katz, Bachynski, and Klein (1993) measured visual evoked potentials (VEPs) in response to dynamic random dot stereograms (RDSs) displaying regions that continuously alternated between crossed and uncrossed horizontal disparity. As a consequence, these regions jumped from above (crossed disparity) to below (uncrossed disparity) a reference surface (see also Petrig, Julesz, Kropfl, Baumgartner, & Anliker, 1981). According to the results of these studies, VEP signals to the stereograms can be observed after approximately 3 months of age.

Infant stereopsis: Looking studies using line stereograms and RDSs

Looking studies on infants' responsiveness to horizontal disparity information have used either line stereograms or RDSs. Birch, Gwiazda, and Held (1982) presented infants with two line stereograms. Each line stereogram consisted of two half-images. In one line stereogram, some lines were shifted laterally in one of the half-images to induce horizontal disparity. The half-images of the other line stereogram were identical and, as a consequence, displayed zero disparity. Onset of stereopsis was defined as the age from which, onward, the infants spontaneously preferred the stimulus containing a 58-min horizontal disparity over the stimulus containing zero disparity. Birch et al. (1982) established that mean age of onset of stereopsis was 14.8 weeks for crossed disparity and 16.8 weeks for uncrossed disparity (see also Birch, 1985; Birch, Shimojo, & Held, 1985; Held, Birch, & Gwiazda, 1980). Gwiazda, Bauer, and Held (1989) found an earlier onset of responsiveness to a 32-min crossed horizontal disparity in female (9.1 weeks) than in male (12.1 weeks) infants (see also Held, Thorn, Gwiazda, & Bauer, 1996).

Consistent with the line stereogram studies, several studies using RDSs found that visual sensitivity to horizontal disparity emerges after 3 months of age (e.g., Birch & Petrig, 1996; Brown, Lindsey, Satgunam, & Miracle, 2007; Fox, Aslin, Shea, & Dumais, 1980). More recent research suggests that infants respond to horizontal disparity information even from approximately 8 weeks of age onward (Brown & Miracle, 2003; Kavšek, 2013b; Wattam-Bell, 2003).

Binocular rivalry in infants: VEP studies

Binocular rivalry occurs when the eyes receive two different images. If the difference between the images is sufficiently large, our visual system is unable to combine the images into a coherent representation. Instead, one image dominates awareness, while the other image is suppressed. VEP studies have measured differential brain responses to dynamic random dot correlograms (RDCs), which alternated between a correlated and an anticorrelated phase. In the correlated phase, the dot patterns presented to the eyes have been identical; in the anticorrelated (rivalry) phase, the dot pattern presented to one eye has been the negative of the dot pattern presented to the other eye. These VEP studies have indicated that the infant brain processes the information embedded in dynamic RDCs from approximately 3 months of age onward (e.g., Birch & Petrig, 1996; Braddick et al., 1980; Petrig et al., 1981).

Binocular rivalry in infants: Looking studies

Again, consistent with these VEP studies, research applying looking techniques has observed that infants prefer fusible over nonfusible, rivalrous gratings from approximately 3 months onward (e.g., Birch et al., 1985; Gwiazda et al., 1989; Shimojo, Bauer, O'Connell, & Held, 1986). More recent research has indicated that infants' visual avoidance of rivalrous gratings becomes significant even from approximately 8 weeks onward (Brown & Miracle, 2003; Kavšek, 2013a).

Infant stereopsis: Reaching and habituation–dishabituation studies

Unfortunately, the VEP and looking studies on infant responsiveness to line stereograms and to RDSs do not unequivocally demonstrate infants' ability to extract the depth information specified by horizontal disparity (Braddick, 1996). More specifically, the VEP studies might simply show the ability to respond to variations in horizontal disparity. Moreover, several looking studies observed a preference for horizontal disparity information over zero disparity (e.g., Fox et al., 1980; Held et al., 1980). In these studies, however, the infants might simply have extracted disparity per se. Birch et al. (1982) therefore tested infants' sensitivity to a stimulus containing vertical disparity and to a stimulus containing an extremely large horizontal disparity. Both stimuli do not generate the impression of depth in adults. According to the results, the infants failed to react to these control stimuli. This finding implies that infants are sensitive to a limited range of *horizontal* disparities, instead of responding to disparity as such. The investigation of infants' ability to perceive depth from horizontal disparity requires other experimental designs. Reaching studies provide more direct evidence that infants are able to extract stereoscopically specified depth. The preferential-reaching technique is based on the observation that infants, from 4 to 5 months of age onward, when presented with two objects at different distances, reach for the one that is nearer (e.g., Yonas & Granrud, 1985). Studies using this technique found that 5-month-old infants perceive distance from pictorial depth cues (e.g., Corrow, Granrud, Mathison, & Yonas, 2012; Kavšek & Granrud, 2013). In these studies, infants were shown two equidistant objects. Pictorial depth cues specified that one of the objects was nearer than the other. Under monocular viewing conditions, the illusory depth difference is very powerful. Under binocular viewing conditions, however, binocular information specifies that the objects are equidistant. The infant participants reached preferentially for the apparently nearer object under monocular, but not under binocular, viewing conditions. This finding provides evidence that infants respond to pictorial, as well as to binocular, depth information from 5 months of age onward. In a related paradigm, Granrud (1986) observed that disparity-sensitive 4-month-old infants reached more consistently for the nearer of two objects than did 4-month-old infants who did not show evidence of sensitivity to disparity. Gordon and Yonas (1976) presented infants 5 months of age with stereoscopically projected virtual objects. When the virtual object appeared to be within reach, the infants reached more consistently for the object than when the virtual object appeared to be out of reach (see also Bechtoldt & Hutz, 1979; Yonas, Oberg, & Norcia, 1978).

In addition, several looking studies have assessed infants' ability to respond to object shape specified by horizontal disparity. In a habituation–dishabituation study, Yonas, Arterberry, and Granrud (1987) established that disparity-sensitive infants 4 months of age distinguished between stereoscopically specified objects. Appel and Campos (1977) found that 8-week-old infants detected the difference between a nonstereoscopic, two-dimensional representation of an object and a stereoscopic, three-dimensional representation of the same object (see also Hutz & Bechtoldt, 1980).

Infant stereopsis: Limitations of earlier studies

The reaching studies on infant sensitivity to stereoscopic depth information, as well as the looking studies on infant sensitivity to stereoscopically defined object information, used shadow-casting devices to create a stereoscopic impression. According to Aslin and Dumais (1980), in the shadow-casting technique, the screen lacks contour information to adjust convergence to the screen plane. Therefore, the infants who participated in the studies using shadow-casting devices might simply have bifoveally fixated the two half-images, rather than the screen plane. Since this situation does not contain horizontal disparity, the infants might have used convergence angle as a depth cue. Furthermore, in the line stereogram studies (e.g., Gwiazda et al., 1989), as well as in the studies employing static RDSs (Brown et al., 2007; Brown & Miracle, 2003; Wattam-Bell, 2003), the relative shift of the area defined by horizontal disparity can be detected by alternate monocular views (Birch, 1993). Similarly, in the looking studies displaying stereoscopically defined objects, the infants might have responded to monocular information, the differences between the half-images. For example, in the Appel and Campos (1977) study, the infants might have detected that the nonstereoscopic stimulus was composed of identical half-images, while the stereoscopic stimulus was composed of two different half-images (but see Yonas et al., 1987).

Goals of the study

Prior looking studies have shown that infants are able to detect horizontal disparity information (e.g., Wattam-Bell, 2003). Moreover, VEP studies suggest that the infant brain responds differentially to crossed versus uncrossed horizontal disparities (e.g., Skarf et al., 1993). The present study explored whether these findings could be replicated, applying a preferential-looking method. Three experiments were conducted. Experiments 1 and 2 tested whether infants 5 months of age were able to respond to crossed and uncrossed horizontal disparity. Experiment 3 examined whether 5- to 6-month-old infants were also able to perceive the difference between crossed and uncrossed horizontal disparity. Preferential-reaching studies established that infants reach more consistently for the nearer of two objects from 4 to 5 months onward. In addition, Tsuruhara, Corrow, Kanazawa, Yamaguchi, and Yonas (2014) investigated 4- and 5-month-old infants' looking behavior toward a target that was specified as closer versus a target that was specified as farther away by pictorial depth cues. They found that the infants preferred looking at the apparently nearer target under monocular viewing conditions, under which the pictorial depth cues evoked an impression that the targets were at different distances, but not under binocular viewing conditions, under which binocular information specified that the targets were equidistant. On the basis of these results, it was tested whether infants would visually prefer a stimulus containing crossed horizontal disparity, an apparently closer stimulus, over a stimulus containing uncrossed horizontal disparity, an apparently more distant stimulus. If this holds true, it would substantiate that infants are able to extract the differential spatial meaning of crossed and uncrossed disparities.

Dynamic RDSs were used in which the dots were continuously renewed. As a consequence, detectable differences between the half-images were eliminated. Experiments 1 and 2 investigated whether infants 5 months of age displayed a spontaneous preference for both a stimulus containing crossed horizontal disparity and a stimulus containing uncrossed horizontal disparity over a stimulus without horizontal disparity. In the experimental stimuli, two squares defined by disparity were shown on the right and on the left halves of a computer monitor. One square was defined by either crossed (Experiment 1) or uncrossed (Experiment 2) horizontal disparity, the other by vertical disparity. The square defined by crossed horizontal disparity appeared to float above the reference surface; the square defined by uncrossed horizontal disparity appeared to be shifted below the reference surface. The comparison square with vertical disparity did not evoke a depth effect but, nevertheless, appeared as a hazy square. Spontaneous preferences for the crossed and uncrossed horizontal disparity targets over the vertical disparity target can be attributed to the ability to respond to *horizontal* disparity, instead of disparity as such. In Experiment 3, infants 5 to 6 months old were presented with a stimulus display containing a square defined by crossed disparity on one side and a square defined by uncrossed disparity on the other. The infants who participated in Experiment 3 were a bit older (5 to 6 months) than the infants who were tested in Experiments 1 and 2 (5 months). Age range was slightly different because the participants were drawn from samples of other studies on the visual abilities in various age groups. Experiment 3 was based on the assumption that infants 5 to 6 months of age are able to extract both crossed and uncrossed horizontal disparities. Prior research has shown that responsiveness to horizontal disparity can be reliably observed from approximately 2 to 5 months of age onward. Moreover, Experiments 1 and 2 established that sensitivity to both crossed and uncrossed horizontal disparity is present in 5-month-old infants. It can therefore be assumed with certainty that the capability of responding to crossed, as well as to uncrossed, horizontal disparity was present in the age group investigated in Experiment 3. In all experimental stimuli, both squares moved continuously back and forth. Motion is highly salient for infants and attracts their attention (e.g., Bertenthal & Bradbury, 1992).

Experiment 1: Crossed horizontal disparity versus vertical disparity

Method

Participants

Nineteen full-term infants (10 girls, 9 boys; mean age = 151 days, range = 145 to 160 days) participated in the experiment. None of the infants had known or suspected abnormalities; this was also the case in the other experiments. Moreover, in all experiments, no data needed to be excluded from data analysis because of a position bias of 95% or more, a preference for either the left or right target on at least 95% of the trials (Haaf & Diehl, 1976). No infant had to be omitted from the final data set of the first experiment due to fussing, sleepiness, or other sources of error. 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). Data protection was guaranteed. The parents received either 5 Euros or a toy animal. Parents gave informed consent before testing was conducted. The study was approved by the ethics committee of the Department of Psychology at the University of Bonn.

Apparatus

The apparatus, stimuli, and procedure have been described in full detail in Kavšek (2013b). Each infant was seated on a parent's lap in front of a 47.4 × 29.6 cm flat LCD autostereoscopic 3-D monitor (SeeFront SF 2223). Viewing distance was 45 cm. The center of the monitor was at the infant's eye level. Two black side panels (82 × 170 cm) blocked the experimental room and the experimenters from the infant's view. The room was dark except for light from a lamp behind the front panel and from the computer screens in the experimental room.

Two small cameras above the 3-D computer screen monitored the infant. One camera was a face-tracking device. It was connected to the software of the autostereoscopic monitor. The software was handled using an additional computer monitor, which also showed the shots of the face-tracking camera. Frames around the contour of the face, the eyes, and the nose signaled whether the face-tracking camera correctly captured the infant's face.

Lenticular lenses on top of the 3-D screen split the image into two parts, one for the right eye and one for the left eye. Using the information from the face-tracking camera, the monitor's software automatically determined the position of the infant's face and adapted the half-images to that position. The autostereoscopic device needs about $\leq$0.25 s to restore the stereoscopic effect after rapid head movements. The stereoscopic device may temporarily lose track of the face—for instance, if the face moves outside the scope of the tracking camera or if the head is turned backward. In this case, the device typically needs $\leq$0.5 s to find the face again and restore the stereoscopic effect. The second camera was used to observe the infant's looking patterns.

Stimuli

The experimental stimuli shown to the infants were two dynamic RDSs, which were made up of black and white square elements. Each RDS consisted of two half-images. Overall size of the stereograms was 47.4 (55.55°) × 23.7 cm (29.51°). The remaining parts of the monitor were black. Size of the square random dot elements was 0.393 cm (0.5°). Luminance of the white random dots was 169 cd/m^2; luminance of the black random dots was $\leq$0.2 cd/m^2. Contrast ratio, hence, was $\geq$845:1. In the RDSs, 56% of the square elements were white, and 44% of the square elements were black, the maximum density value attainable by our software (IDL). The random dots were renewed at a rate of 5 times a second. On the right side of one of the RDSs, a 7.87 × 7.87 cm (10°) square defined by a crossed horizontal disparity of 0.5° moved continuously back and forth. On the left side of that RDS, a square defined by a vertical disparity of 0.5° moved in phase. In the remaining RDS display, position of the square targets was exchanged. The 0.5° disparity value was chosen because it has been successfully used in earlier studies as well (e.g., Birch, 1985; Gwiazda et al., 1989, Kavšek, 2013b). The square targets were separated by a 15.87-cm (20°) gap. They moved with a speed of 3.93 cm per second (5°/s). Path length from the left to the right or vice versa was 7.87 cm (10°). The random dots within the square targets were renewed at the same rate as were the random dots in the remaining parts of the RDSs. They could not be seen when looking with one eye only at the stereograms. With two eyes, however, the target with horizontal disparity was perceived as a square floating in front of the background. The vertical disparity target generated no depth effect and was perceived as a blurred square shape.

Before the first trial and between trials, an attention-getter was shown. The attention-getter consisted of four 2.5 (3.18°) × 2.5 cm squares, which were symmetrically arranged in the middle of the screen. Each square had a different color (magenta, red, blue, and green). Distance between the squares was 2.5 cm. They were set against a light gray background and rotated clockwise around their center. One rotation lasted 8 s.

At the beginning of a rotation, a short jingle chimed. As soon as the infant looked at the attention-getter, a trial was initiated.

Procedure

Each infant was brought to the test room by one parent and was seated on the parent's lap. The parent was asked not to point at the screen and influence the child's looking behavior during the experiment.

At the beginning of the test session, the attention-getter was presented. When the infant looked at the attention-getter, the first RDS was shown. Each experimental session included between four (minimum) and seven (maximum) blocks of four forced choice preferential-looking (FPL) trials. On two trials of each block, the crossed horizontal disparity square target was embedded in the left side of the RDS, and the vertical disparity square target was embedded in the right side. On the remaining two trials, the positions of the square targets were exchanged. To control sequence effects, 12 different orders of seven blocks of four trials were randomly constructed. For each participant, 1 order was randomly drawn from these 12 orders of seven trial blocks. The participant was then tested with this order.

The first block of trials in a test session served as a warm-up phase. The infant was accustomed to the stimuli and received the opportunity to detect the square target defined by horizontal disparity. Moreover, the experimenter who collected the data was made familiar with the infant's looking behavior. The data from this block of trials were not included in the final data set. Data from the subsequent trials were included in the final data set if the infant accomplished a minimum of 12 trials. Beyond that, trials were administered until the infant became too distracted or too tired or until the maximum of 24 trials was attained. Mean number of completed trials was 18.05 (*SD* = 4.59).

One experimenter monitored whether the face-tracking camera captured the infant's face. If the camera failed to capture the infant's position, the trial was broken off and started anew. This, however, occurred very rarely. The experimenter also controlled the presentation of the stimuli. A second experimenter observed the infant's looking behavior on a computer monitor attached to the second camera. The observer was blind to the position of the square target defined by horizontal disparity on the stereoscopic monitor at any time. On each trial, he judged whether the infant preferred to look at either the left or the right square target by pressing buttons. This FPL judgment (e.g., Teller, 1997) was based on the infant's direction of first fixation, number of looks to each side, duration of looking time at each square target, and eye widening (e.g., Civan, Teller, & Palmer, 2005). A trial was valid only if the observer made a forced choice judgment within 10 s after trial onset. Otherwise, the trial was broken off, and the next trial was initiated. Mean trial duration, the mean duration needed to pass a judgment, was 4.58 s (*SD* = 0.48 s). The observer's pressing of the buttons was recorded by a computer. The dependent variable was defined as the number of the trials on which the observer's judgment of the infant's gaze direction matched the actual location of the square target with crossed horizontal disparity divided by the total number of completed trials, the total number of trials on which the observer made a judgment about the (left or right) direction of the infants' looking preference. A percent match score higher than .50 indicated a natural preference for the crossed horizontal disparity square target over the vertical disparity square target.

The looking behavior of the participants was later recoded from the film recordings made during the experimental sessions to obtain a measure of interobserver agreement. Pearson correlation was $r = .969$ for the percent-match/relative-preference scores.

Results

Preliminary data analyses found no effect of *sex* in any of the experiments. The sex variable was therefore omitted from subsequent data analyses. As was expected, the infants looked more often at the square target defined by crossed horizontal disparity than at the square target defined by vertical disparity (M = .69, SD = .17). A one-sample t test was conducted to test whether the mean relative preference score was significantly different from .50, the chance probability. The t statistics yielded a significant (α = .05) result, $t(18)$ = 4.69, two-tailed $p \leq .001$, effect size d = 1.08. The effect size is large (>0.80). It was estimated according to Cohen (1977; Faul, Erdfelder, Buchner, & Lang, 2009). Sixteen out of the 19 participants had a relative preference score above .50. A binomial test indicated that the proportion of infants who preferred looking at the square target defined by crossed horizontal disparity was significantly different from the chance probability (.50), two-tailed p = .004.

The second experiment was conducted to ascertain whether infants 5 months of age are also sensitive to uncrossed horizontal disparity.

Experiment 2: Uncrossed horizontal disparity versus vertical disparity

Method

Participants

Another group of 19 full-term healthy infants (10 girls, 9 boys; mean age = 153 days, range = 145 to 166 days) was investigated in the second experiment. One additional infant had to be omitted because the infant was too distracted to be tested.

Apparatus, stimuli, and procedure

The apparatus and procedure were exactly the same as in the first experiment. The RDSs shown in the second experiment were constructed from the RDSs used in the first experiment by replacing the square targets defined by crossed horizontal disparity by square targets defined by uncrossed horizontal disparity. This was accomplished by simply exchanging the half-images of the RDSs from Experiment 1. Hence, the second experiment tested whether the participants exhibited a spontaneous preference for a square target with a 0.5° uncrossed horizontal disparity over a square target with a 0.5° vertical disparity. Mean number of completed FPL trials was 17.68 (*SD* = 3.50). Mean trial duration was 5.14 s (*SD* = 1.50 s). The dependent variable was the relative number of the trials on which the observer's judgment of the infant's gaze direction matched the actual location of the square target with uncrossed horizontal disparity. Interobserver agreement was $r = .89$ for the relative preference scores from the 19 babies.

Results

The infants looked significantly more often at the uncrossed horizontal disparity target than at the vertical disparity target ($M = .75$, $SD = .14$), $t(18) = 8.08$, two-tailed $p \leq .001$, $d = 1.85$. Eighteen out of the 19 infants displayed a natural preference for the uncrossed horizontal disparity target, two-tailed $p \leq .001$, according to a binomial test.

In the next step, the mean relative preference scores from Experiments 1 and 2 were compared with each other to assess whether either crossed or uncrossed horizontal disparity evoked a stronger natural preference. A *t* test for independent groups revealed no significant difference between the mean relative preferences, $t(36) = -1.24$, two-tailed $p = .223$.

In sum, infants 5 months of age prefer both crossed and uncrossed horizontal disparity over vertical disparity. The mean relative preference was higher for the uncrossed horizontal disparity target ($M = .75$) than for the crossed horizontal disparity target ($M = .69$). However, the difference between theses scores was not statistically significant. The goal of the third experiment was to directly compare crossed with uncrossed horizontal disparity. It was predicted that infants should display a preference for crossed horizontal disparity over uncrossed horizontal disparity if their visual attention is governed by a natural tendency to attend to the (apparently) nearer of two targets.

Experiment 3: Crossed versus uncrossed horizontal disparity

Method

Participants

The sample of Experiment 3 included 17 infants (8 girls, 9 boys; mean age = 170 days, range = 160 to 181 days). One additional infant was excluded from the final sample because it was too distracted. Mean number of completed FPL trials was 17.59 (*SD* = 3.04). Mean trial duration was 5.30 s (*SD* = 0.58 s). Interobserver agreement was $r = .979$.

Apparatus, stimuli, and procedure

Again, the apparatus and the procedure were the same as in Experiment 1. Two RDSs were constructed from the stimuli used in Experiments 1 and 2 by combining the square targets defined by 0.5° crossed horizontal disparity with the square targets defined by 0.5° uncrossed horizontal disparity. As a consequence, the RDSs consisted of a square target that appeared to move back and forth above the reference surface on one side and a square target that appeared to move back and forth below the reference surface. In one RDS, the square target with crossed horizontal disparity was positioned on the right side, and the square target with uncrossed horizontal disparity was positioned on the left side. In the other RDS, the positions of the square targets were reversed. The dependent variable was the relative preference for the square target with crossed horizontal disparity over the square target with uncrossed horizontal disparity.

Results

The participants preferred looking at the target defined by crossed horizontal disparity ($M = .68$, $SD = .21$), $t(16) = 3.68$, two-tailed $p = .002$, $d = 0.89$. A binomial test indicated that the proportion of infants with a relative preference score above .50 was significant, two-tailed $p = .013$. More specifically, 14 out of the 17 participants looked more often at the square target with crossed horizontal disparity than at the square target with uncrossed horizontal disparity.

Discussion

The findings confirm earlier studies according to which the ability to respond to horizontal disparity emerges at approximately 2 to 5 months of age. When presented with either crossed (Experiment 1) or uncrossed (Experiment 2) horizontal disparity versus vertical disparity, infants 5 months of age preferred looking at the horizontal disparity patterns. The vertical disparity target controlled whether the infants' looking was simply governed by a tendency to prefer disparity information per se. If this were the case, the infants would have looked equally often at both square targets in Experiments 1 and 2. The significant results obtained in these experiments thus indicate that the infants responded to *horizontal* disparity information. Moreover, they were obviously able to detect both crossed and uncrossed horizontal disparity.

Several studies have recorded infant VEP responses to dynamic RDSs that alternated between crossed and uncrossed horizontal disparity (e.g., Birch & Petrig, 1996; Petrig et al., 1981). According to the results of these studies, clear VEPs were found from approximately 3 months of age onward. Experiment 3 extended these findings by providing evidence for a clear visual response in infants 5 to 6 months of age to dynamic RDSs displaying a crossed versus an uncrossed horizontal disparity. More specifically, the infants preferred looking at a square target specified by a 0.5° crossed horizontal disparity over a square target specified by a 0.5° uncrossed horizontal disparity.

However, in Experiment 3, instead of extracting the difference between crossed and uncrossed horizontal disparity, the infants might have simply responded to the crossed horizontal disparity. More specifically, they might have perceived the crossed, but not the uncrossed, horizontal disparity. If this were the case, the spontaneous preference for the crossed horizontal disparity observed in the experiment would parallel the preference for crossed horizontal disparity over vertical disparity established in Experiment 1 (see also Brown et al., 2007) and for crossed horizontal disparity over zero disparity established in earlier studies (e.g., Birch & Salamão, 1998; Gwiazda et al., 1989). Experiments 1 and 2 were conducted to ensure that infants are able to detect both the crossed (Experiment 1) and the uncrossed (Experiment 2) horizontal disparity used in Experiment 3. In fact, the results of Experiments 1 and 2 substantiated that infants display strong spontaneous preferences for a 0.5° crossed, as well as for a 0.5° uncrossed, horizontal disparity over a 0.5° vertical (control) disparity. Furthermore, the only difference between the critical targets in Experiment 3, the square targets defined by either crossed or uncrossed horizontal disparity, was the relative positions of the half-images generating these targets. One target can be constructed from the other by simply exchanging the half-images sent to the eyes. Due to the use of dynamic RDSs, the relative positions of the targets within the half-images could not be detected by alternate eye closure. As a consequence, it is very likely that the infants' visual response found in Experiment 3 is, indeed, based on the ability to distinguish between crossed and uncrossed horizontal disparity.

The perception of the difference between crossed and uncrossed horizontal disparity does not unequivocally establish that the infants responded to stereoscopically specified depth and shape. Reaching studies found that infants 5 to 6 months of age grasp preferentially for an object that is specified as nearer than another object by kinetic (e.g., Condry & Yonas, 2013; Craton & Yonas, 1988), pictorial (for a review, see Kavšek, Granrud, & Yonas, 2009), and binocular cues to depth (e.g., Gordon & Yonas, 1976; Granrud, 1986). Tsuruhara et al. (2014) presented 4- and 5-month-old infants with two objects, one of which was specified as nearer than the other by pictorial depth cues. According to the results, the infants looked preferentially at the apparently nearer object. Congruent with these research findings, the present study observed a visual preference for a square target defined by crossed horizontal disparity over a square target defined by uncrossed horizontal disparity. The parallel findings provide evidence to suggest that the infants in Experiment 3 responded to the differential depth information provided by crossed versus uncrossed horizontal disparity: They looked more often at the square target with crossed horizontal disparity because it appeared nearer than the square target with uncrossed horizontal disparity. Nevertheless, this conclusion has to be validated by additional research. For example, one might observe infant reaching toward the stimuli employed in Experiment 3. Moreover, future research should also examine infants younger than 5 to 6 months of age to reveal the onset of the ability to extract the spatial meaning of horizontal disparity information.

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