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Infants' ability to respond to depth from the retinal size of human faces: Comparing monocular and binocular preferential-looking

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Abstract

To examine sensitivity to pictorial depth cues in young infants (4 and 5 months-of-age), we compared monocular and binocular preferential *looking* to a display on which two faces were equidistantly presented and one was larger than the other, depicting depth from the size of human faces. Because human faces vary little in size, the correlation between retinal size and distance can provide depth information. As a result, adults perceive a larger face as closer than a smaller one. Although binocular information for depth provided information that the faces in our display were equidistant, under monocular viewing, no such information was provided. Rather, the size of the faces indicated that one was closer than the other. Infants are known to look longer at apparently closer objects. Therefore, we hypothesized that infants would look longer at a larger face in the monocular than in the binocular condition if they perceived depth from the size of human faces. Because the displays were identical in the two conditions, any difference in looking-behavior between monocular and binocular viewing indicated sensitivity to depth information. Results showed that 5-month-old infants preferred the larger, apparently closer, face in the monocular condition compared to the binocular condition when static displays were presented. In addition, when presented with a dynamic display, 4-month-old infants showed a stronger 'closer' preference in the monocular condition compared to the binocular condition. This was not the case when the

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faces were inverted. These results suggest that even 4-month-old infants respond to depth information from a depth cue that may require learning, the size of faces.

Keywords

Depth; Face; Preferential looking; Infant; Familiar size; Relative size

1. Introduction

Adults perceive the distance and 3-D shape of objects using many visual depth cues (Cutting & Vishton 1995; Howard & Rogers 2002). Certain cues, such as shading, provide spatial information when a scene is viewed monocularly and without motion; these depth cues are traditionally referred to as 'pictorial depth cues.' Previous developmental studies have provided evidence that infants older than 6 months-of-age have the ability to perceive depth from pictorial cues (e.g. Tsuruhara, Sawada, Kanazawa, Yamaguchi & Yonas, 2009; Tsuruhara, Sawada, Kanazawa, Yamaguchi, Corrow & Yonas, 2010; Yonas, Pettersen & Granrud, 1982). On the other hand, it is less clear whether infants younger than 6 months-of-age are sensitive to pictorial depth information. The present study examined the development of sensitivity to depth provided by a pictorial depth cue that may require learning, the correlation between the retinal size of a human face and its distance.

Geometrically, the visual angle subtended by an object is inversely proportional to its distance from an observer. Thus, if there is little variation in the size of a class of objects, such as is the case with human faces, and an observer *is familiar with* the class of objects, then an object subtending a larger retinal size may be perceived as closer to the observer than an object of the same class subtending a smaller retinal size. Additionally, if an observer makes an assumption of what the typical size of an object is, then the observer could use the retinal image size to estimate the absolute distance to the object. Both cases have been described as 'familiar size' though the former case only requires an assumption that the familiar object class varies little in size, whereas the latter case requires an assumption about the typical size of the class of objects.. The present study deals with the former case, comparing looking preference to two different face images, presented at the same distance, one smaller than the other.

The first study to examine infants' sensitivity to familiar size as a pictorial cue to depth (Yonas et al., 1982) presented two photographs of female faces, one larger than the other, to 5- and 7-month-old infants. Each photograph was presented one-at-a-time, at the same distance, under both monocular and binocular viewing conditions. During monocular viewing, familiar size provided information for depth. During binocular viewing, familiar size information for depth conflicted with binocular information provided by stereopsis/convergence. Consistent with their hypothesis, 7-month-old infants *reached* for a longer period of time to the larger face under monocular viewing and equally to the two faces under binocular viewing. These results suggest that 7-month-old infants perceived the larger face as closer under monocular viewing (Field, 1976; Gordon & Yonas, 1976; Yonas, Cleaves & Pettersen, 1978). Because the display was identical in both conditions, it is unlikely that

results could be explained by a preference for larger faces, independent of the perceived distance.

However, in Yonas et al. (1982), 5-month-old infants did not show evidence of sensitivity to pictorial depth provided by familiar size information. Regardless, we cannot conclude the null hypothesis that infants of this age group are unable to perceive depth from pictorial depth information. In fact, Kavsek, Granrud, and Yonas (2009) completed a meta-analysis of the studies examining the development of sensitivity to pictorial depth information using reaching as a dependent measure. With this approach, they found that 5-month-old infants exhibit sensitivity to depth from pictorial depth cues. Unfortunately, reaching cannot be used as a dependent measure for infants younger than 5-months-old because they do not yet reach reliably. However, it is possible that a different approach may yield significant findings in even younger infants.

To address this issue, several researchers have measured infants' looking behavior, rather than reaching behavior, to examine the development of visual and cognitive skills. This method has provided conflicting results regarding infants' sensitivity to pictorial depth cues (see Kavsek, Yonas & Granrud, 2012, for review). Some studies measured infants' preferential looking and concluded that infants as young as 3-months (e.g. Bhatt & Waters, 1998) and 4-months (Shuwairi, Albert & Johnson, 2007) have sensitivity to pictorial depth cues. For example, 3-month-old infants discriminated between cubes that varied in orientation as specified by shading and line junction cues. This preference was not observed when infants were presented with control displays that did not appear to adults as 3-D shapes (Bhatt & Waters, 1998). On the other hand, studies using the habituation/dishabituation method (e.g. Tsuruhara et al. 2009, 2010) have found evidence of sensitivity to pictorial depth cues around 6-months, but not in younger infants.

Kavsek et al. (2012) meta-analyzed the previous looking studies and suggested that 'we cannot rule out the possibility that young infants respond to two-dimensional, proximal stimulus differences that co-vary with the critical depth differences (Kavsek et al., 2012, p. 126).' They also suggested, however, that the studies showing sensitivity to pictorial depth cues only in older infants might underestimate younger infants' perceptual abilities. They indicated that many of these studies required infants to extract 3-D form information – a skill that may develop after the ability to visually judge the difference between 'closer' and 'farther.'

Considering these arguments, it is worthwhile to explore younger infants' sensitivity to pictorial depth cues by comparing monocular and binocular preferential looking with the *same* display. This method is less demanding for infants and minimizes the possibility that infants could respond to only 2-D, proximal information. We measured 4- and 5-month-old infants' preferential looking to two simultaneously presented faces, one large and one small. It has been previously demonstrated that infants look longer to an object when it is closer than when it is farther away (McKenzie & Day, 1972). Therefore, we here apply the same logic as previously reported in reaching studies – that infants will look longer at an apparently nearer display than one that appears further away. More specifically, we expect a stronger preference for the larger, apparently closer, face under monocular viewing

conditions compared to binocular viewing conditions, indicating sensitivity to depth perception from the size of faces. Because the displays were identical in the two conditions, except for binocular information for depth, such an outcome reduces the plausibility of other explanations for looking preferences that are independent of the processing of depth information.

However, the conclusions that can be made from this method may be more limited than the conclusions that can be made from reaching studies of depth perception. Given that infants are not required to reach to the display, we emphasize the possibility that this method might simply measure the ability to judge two stimuli as 'nearer' and 'further' without requiring a judgment about the specific distance from viewer to object, as might be required in reaching studies of depth perception. Although, we emphasize that a judgment of 'near' versus 'far' is, nonetheless, a judgment of relative depth.

Using this approach, we recently demonstrated that 4- and 5-month-old infants are sensitive to pictorial depth from height-in-the-picture plane, with infants looking longer at a lower, apparently closer figure under monocular than binocular viewing conditions. One limitation of this method, however, is that it requires infants' ability to use stereopsis, which has been reported to develop around 4-months-of-age in previous behavioral (Birch, Gwiazda & Held, 1982; Fox, Aslin, Shea & Dumais, 1980; Held, Birch & Gwiazda, 1980; Teller, 1982) and neural (Braddick et al., 1980) studies. Thus, the present study examined 4- and 5-month-old infants, rather than younger infants.

We also examined the effect of presenting moving displays on preferential looking behavior. In Experiment 2, we added a smiling movement to both of the simultaneously presented faces. Previous studies have shown that motion facilitates face perception in infants as young as 2 and 3 months-of-age (Ichikawa, Tsuruhara, Kanazawa & Yamaguchi, 2013; Otsuka et al., 2009). For example, Otsuka et al. (2009) showed that 3- and 4-month-old infants were able to learn an unfamiliar female face faster when the internal facial features were in motion than when they were static. Therefore, the additional movement could make it easier for infants to perceive the stimulus as a face and, as a result, respond to depth from the retinal size of the stimuli.

In addition, we presented inverted face pairs as well as upright face pairs. Previous research has demonstrated that inverted faces are perceived as less face-like than upright faces in 4- (Turati, Sangrigoli, Ruel & de Schonen, 2004) and 5-month-old infants (Rose, Jankowski & Feldman, 2008). Even newborns orient their gaze more frequently toward an upright face than an inverted one (Johnson, Dziurawiec, Ellis & Morton, 1991). Therefore, we predicted that the difference between monocular and binocular viewings would differ between upright and inverted presentation because infants are less likely to perceive depth from size with inverted faces.

It is also important to consider the effect of stimulus size on infants' looking behavior. Slater, Mattock, and Brown (1990) demonstrated that infants prefer to look at the larger of two objects. Therefore, our binocular and face-inverted conditions additionally help to control for the effect of stimulus size. If infants simply prefer to look at the larger of two

objects, then, they should do so in all cases regardless of viewing condition (monocular versus binocular) or orientation (upright versus inverted). Furthermore, in the unlikely event that viewing faces *monocularly* biases infants to prefer the larger face irrespective of depth information, then infants should prefer to look at the larger face in any monocular viewing condition, regardless of face orientation.

2. Experiment 1

2.1 Method

2.1.1 Participants—The final sample consisted of 24 infants; twelve four-month-olds (5 females and 7 males) and twelve five-month-olds (5 females and 7 males). The mean age of the younger group was 118.8 days ($SD = 7.5$ days) and the older group, 148.5 days ($SD = 7.8$ days). Data from an additional 3 infants were excluded due to fussiness (1), or a total looking time in the three test trials of each condition of less than 8 seconds (2). The participants were recruited by newspaper ads and follow-up telephone calls. All participants were full-term at birth.

2.1.2 Apparatus—Each infant sat on his or her parent's lap in front of a 22-inch CRT monitor (Mitsubishi DP2070SB), on which all stimuli were displayed. The CRT monitor was surrounded by a three-sided black enclosure so that only the screen was visible to the infants. Each infant was seated approximately 40 cm from the screen. The resolution of the monitor was set at 1024×768 pixels. The room was dark during the trials and two speakers were positioned on either side of the monitor. A CCD camera, located just below the monitor, was used to videotape the infant's behavior throughout the experiment. The experimenter observed each infant's behavior via a TV monitor connected to the camera.

2.1.3 Displays—Two different faces of different sizes were presented simultaneously; one on the left and one on the right side of the screen (Figure 1). The stimuli were three (labeled A, B, and C, respectively) elliptical-shaped, full-color pictures of female faces in their early twenties. Therefore, there were six pairs of faces: large A and small B, large A and small C, large B and small C, small A and large B, small A and large C, small B and large C. The static face pictures were extracted from digital videos of females smiling naturally. We extracted images with the largest smiles for each person in order to attract the infants' attention.

For each age group, all infants viewed both upright and inverted faces under both monocular and binocular conditions. In each viewing condition, each face pair was presented once for a total of six 10-second trials, three upright and three inverted. Thus, each infant received 12 trials: three monocular-upright trials, three monocular-inverted trials, three binocular-upright trials, and three binocular-inverted trials. For half of the infants, the larger face appeared on the left in two out of the three trials for every combination of upright/inverted faces and monocular/binocular viewings. For the other half, the larger face appeared on the right in two out of the three trials for every combination of upright/inverted faces and viewing condition. Within each viewing condition, the order of the six trials was randomized.

The width and height of the larger faces were 20.0 degrees and 28.3 degrees (respectively) of visual angle, and the smaller faces were 12.0 degrees and 17.0 degrees (respectively). The centers of the two faces were horizontally aligned to the center of the screen. The distance between the center of the screen to the edge of each face was 5.9 degrees (horizontal). Thus, the centers of the two faces were separated by 27.8 degrees.

2.1.4 Procedure—At the start of each trial, a repeating tone accompanied a large flashing asterisk presented in the center of the screen to get the infant's attention. When the infant fixated the center of the screen, the experimenter initiated the trial. The presentation time was fixed at 10 seconds regardless of whether the infant continued looking at the screen or looked away. In the monocular condition, an eye patch was placed over one of the infant's eyes.

2.1.5 Coding—An off-line scorer measured each infant's fixations to the left and right sides of the monitor from the video recordings. Only the infant's looking behavior was visible in the video. Thus, the scorer was unaware of the position of the two faces; the beginning and the end of each trial were indicated by sounds recorded on the video. To compute inter-scorer agreement, a second scorer's measurement of each infant's looking time was obtained for 33% of the total data of each age group. The second scorer was completely naïve to the hypothesis of the study. Inter-scorer agreements (r) for the data of the 4-month-olds were 0.93 and 0.88 in the monocular and binocular conditions respectively, and those for the data of 5-month-olds were 0.94 and 0.90 respectively.

2.2 Results

The mean looking times are shown in Table 1. First, for both age groups, we performed a 2 (viewing condition: monocular vs. binocular) $\times$ 2 (orientation: upright vs. inverted) $\times$ 3 (the order of the trials) ANOVA on the looking times to examine the effect of trial-order. For both age groups, the main effect of trial-order was significant [4-month-olds: $F(2,22) = 4.23$, $p < .03$; 5-month-olds: $F(2,22) = 5.18$, $p < .02$] reflecting the reduction of looking time as the experiment progressed. However, all interactions were not significant indicating that the effect of order was not significantly different between conditions. In other words, although looking time decreased throughout the experiment, this reduction in looking time did not affect any one condition in particular. Therefore, we averaged looking times across all three trials for subsequent analyses.

To test whether infants looked longer at the larger, apparently 'closer', face, a 'closer' preference score was calculated for each infant by dividing the infant's looking time to the larger face by the total looking time to the display for each condition (monocular-upright, monocular-inverted, binocular-upright, binocular-inverted). The mean 'closer' preference scores are shown in Figure 2. To compare the 'closer' preference scores to chance-level (0.5), we conducted two-tailed, one-sample t -tests. The t -tests revealed that preference scores were significantly larger than chance for 5-month-olds with monocularly viewed upright faces [$t(11) = 3.94$, $p < .01$] and for 4-month-olds with binocularly viewed inverted faces [$t(11) = 3.14$, $p < .01$]. No other conditions showed a significant difference than chance.

To examine the effect of experimental condition for each age group, a 2 (age group) $\times$ 2 (viewing condition) $\times$ 2 (orientation) ANOVA was performed. In order to examine the difference between the viewing conditions for each age group/orientation combination, we conducted pairwise comparisons with Bonferroni corrections as planned comparisons. The ANOVA revealed a significant main effect of viewing condition [$F(1,22) = 4.90, p < .05$] and an interaction of age group and viewing condition [$F(1,22) = 4.37, p < .05$]. Tests of simple main effects showed that the difference between the monocular and binocular conditions was significant for 5-month-olds [$F(1,22) = 9.27, p < .01$], but not for 4-month-olds. Though the second-order interaction (age group, viewing condition and orientation) was not significant [$F(1,22) = 1.90, ns.$], pairwise comparisons as planned comparisons showed that the difference between the viewing conditions was significant only for 5-month-olds when the faces were upright [$F(1,22) = 8.53, p < .01$] while no other combinations of the conditions produced a significant difference.

These results demonstrate that 5-month-old infants looked at the larger and apparently closer face significantly longer in the monocular condition than in the binocular condition only when the faces were upright. In contrast, 4-month-old infants did not show a significant difference in looking between the two viewing conditions, regardless of face orientation.

2.3 Discussion

We examined infants' sensitivity to depth specified by the size of a human face. The results were consistent with the notion that the size of upright faces could be a cue for depth in 5-month-olds, while they did not provide evidence of sensitivity to depth information with inverted faces. In contrast, 4-month-old infants did not show evidence of depth perception from the size of faces. This result, however, does not necessarily mean that they do not perceive depth from face-size; especially when considering previous studies which showed younger infants' sensitivity to pictorial depth cues (e.g. Bhatt & Waters, 1998). One possibility for the lack of evidence is that the stimuli might not have been perceived as face-like for the younger infants due to their static nature. To examine this possibility, Experiment 2 increased the realism of the faces by adding a smiling movement to represent the typical kind of movement often seen in faces by infants. Previous studies have shown that moving information facilitates face perception in infants (Ichikawa et al., 2013; Otsuka et al., 2009). Therefore, we hypothesized that both groups of infants might show a larger 'closer' preference in the monocular than binocular condition for dynamic upright faces. Such an outcome would suggest that the failure to find evidence for 4-month-olds' sensitivity to depth information in Experiment 1 might have been due to their difficulty in perceiving the static stimuli as face, rather than a lack of sensitivity.

3. Experiment 2

3.1 Method

3.1.1 Participants—The final sample consisted of 12 four-month-old infants (7 females and 5 males). The mean age was 115.5 days ($SD = 7.2$ days). Data from an additional 3 infants were excluded due to fussiness (1), or a side-bias defined as a tendency to look at

only one side of the screen greater than 90% of the time (2). The participants were recruited by newspaper ads and follow-up telephone calls. All participants were full-term at birth.

3.1.2 Apparatus, displays and procedure—The stimuli used for Experiment 2 were dynamic, smiling faces. A 1.5 second video was presented repeatedly for 10 seconds in each trial. The moving stimuli were made from digital videos of three females. The same models were used as in Experiment 1 and the videos used for the stimuli in Experiments 1 and 2 were recorded in the same day. Each female was instructed to alternate between a neutral and smiling expression, at a speed they were comfortable with, several times. The videos were clipped into ellipse and trimmed to 1.5 seconds as follows: The original videos, which were recorded in 30 Hz, were broken down into sequential static pictures. From these pictures, 45 sequential images, including neutral – smile – neutral changes, were selected. Then, every picture was clipped into an ellipse of the same size of the stimuli in Experiment 1 and each picture was presented sequentially for 33 milliseconds (2 frames of 60 Hz) on the monitor. The largest smile appeared in exactly the middle, the 23rd, picture for all three females so that the smiling movement of the two faces on the display coincided over the course of a trial. The other features of the displays, apparatus, and procedure were identical to those in Experiment 1.

3.1.3 Coding—To compute the inter-scorer agreement, a second scorer's measurement of infant's looking time was obtained from 33 % of the total data. A second scorer was completely naïve to the hypothesis of the study. Inter-scorer agreements (r) were 0.86 and 0.95 in the monocular and binocular conditions, respectively. The other features of the coding were identical to those in Experiment 1.

3.2 Results and Discussion

The mean looking times are shown in Table 1. A 2 (viewing condition) $\times$ 2 (orientation) $\times$ 3 (the order of the trials) ANOVA was performed as in Experiment 1. As in Experiment 1, the main effect of the order of the trials was significant [$F(1,11) = 5.19, p < .05$], but the interactions with the order were not significant in all pairs. Therefore, the looking times across all three trials for each condition were averaged, and 'closer' preference scores were calculated as in Experiment 1.

Figure 3 shows the means and SEs of the 'closer' preference scores. To compare the 'closer' preference scores to chance-level (0.5), we conducted two-tailed one-sample t -tests. The preference scores were significantly larger than chance for upright faces viewed monocularly [$t(11) = 3.94, p < .01$], for inverted faces viewed monocularly [$t(11) = 3.94, p < .01$] and binocularly [$t(11) = 3.14, p < .01$]. The reason is not clear for the lack of the preference of the larger stimuli when the stimuli were upright and viewed binocularly. One possibility is that the dynamic faces were interesting enough and the size did not matter while the depth, closeness to the infants, affected the looking preference.

To examine the effect of experimental condition, a 2 (viewing condition) $\times$ 2 (orientation) ANOVA was performed on the 'closer' preference scores as in Experiment 1. While the main effects of the two factors were not significant [$F(1,11) = 1.86, ns$ for viewing condition; $F(1,11) = 1.27, ns$ for orientation], an interaction of the viewing condition and

orientation was significant [$F(1,11) = 5.12, p < .05$]. Tests of simple main effects showed that the difference between the two viewing conditions was significant for upright faces [$F(1,11) = 11.37, p < .01$], but not inverted faces.

In contrast to the results of Experiment 1, the results of Experiment 2, using the moving face stimuli, showed that the 4-month-old infants looked at the larger and apparently closer face significantly longer in the monocular condition than in the binocular condition, but only when the faces were upright. These results indicate that infants responded to depth information provided by the size of a human face.

4. General Discussion

Adults perceive a larger face as closer to them than a smaller face (Yonas et al., 1982). To confirm 4- and 5-month-old infants' sensitivity to pictorial depth information provided by the size of a human face, we compared infants' preferential looking to a larger, apparently closer, face under monocular and binocular viewing conditions. The results suggest that 5-month-old infants respond to depth specified by the size of faces. Four-month-old infants, however, did not provide such evidence when the faces were static. On the other hand, when the faces made a smiling movement, the results were consistent with the notion that 4-month-olds could perceive depth from this pictorial depth cue.

These results call into question whether infants were utilizing *familiar size* or *relative size* as a cue to depth. There are reasons to believe that both cues influenced looking behavior. The depth cue of *familiar size* requires learning that the objects in a particular class have a consistent size, in addition to learning a correlational relationship between an object's retinal size and its distance. On the other hand, simply learning correlational relationships would make it possible for infants to use *relative size* as a cue to depth. Therefore, one might expect that sensitivity to depth from *relative size* develops before sensitivity to *familiar size*, and that the results of this study reflect infants' sensitivity to *relative size* alone. However, the infants' looking behaviors in the present study were not likely a result of the perceived depth only from *relative size*; if the different looking preferences between monocular and binocular viewing conditions was based solely on *relative size*, then orientation should not have influenced looking times, as was the case for both 4- (Experiment 2) and 5-month-old (Experiment 1) infants. Therefore, it is likely that both familiar size and relative size influenced infant behavior in the present study.

However, as with all behavioral looking studies with infants, it is difficult to make the definitive conclusion that there are no alternative explanations for any set of findings. Therefore, before we posit that the development of sensitivity to depth from the size of a human face is the most likely explanation for our findings, we consider the following alternative explanations. One obvious alternative explanation in this study is the proximal size of the stimuli. Slater and colleagues (1990) demonstrated that infants prefer to look at the larger of two objects. Therefore, it is possible that infants looked at the larger face simply because of its size, rather than its perceived depth. However, this is unlikely for two reasons. First, if infants simply preferred to look at the larger stimulus over the smaller stimulus, then there should have been no difference in looking preference between the

monocular and binocular viewing conditions. Second, even in the unlikely event that infants preferred to look at a larger stimulus, regardless of perceived depth, *only* in the monocular condition, this should have been true for the inverted faces as well. However, we found no evidence to believe that the preference for the larger face was equally strong across all four conditions.

Therefore, a remaining *alternative* explanation for our findings is that infants: a) prefer larger stimuli only when viewing them monocularly *and* b) the inverted stimuli were not perceived configurally and, thus, infants did not differentiate between them. However, there are two caveats to this explanation: a) the infants in Slater et al. (1990) preferred the larger stimulus when viewing a display *binocularly* and b) even if the infants did not differentiate between the two faces, one still subtended a larger retinal size. Although, this alternative explanation seems unlikely, this explanation could also account for the results of studies that used reaching to assess depth perception. Future work should investigate this account.

Given Slater and colleagues' (1990) finding that infants prefer to look at the larger of two objects, it is unclear why we did not consistently find a preference for the larger stimulus regardless of condition. Though the preference was not always significant, Figure 2 shows that the infants in Experiment 1 demonstrated a *tendency* to look at the larger stimulus in the majority of conditions. The only exception was the binocular-upright condition for 5-month-olds, in which the preference for the apparently closer face was less than chance, although not significantly so. In Experiment 2, 4-month-old infants preferred to look at the larger face in all conditions except for, again, the binocular-upright condition. It is possible that, for upright faces under binocular viewing conditions, the size of the display was not as powerful as the attractiveness of the object itself (the human face), making both the large and small display equally appealing in the binocular condition, when convergence information, accommodation, and binocular disparity specified the actual distance of the two faces. Furthermore, the infants in Slater et al. (1990) were newborns. Therefore, it is possible that the general tendency to look at objects with the larger retinal size changes in the months after birth.

Our results also suggest that facial movements facilitate infants' response to depth from the retinal size of faces. In other words, the facial movement may have made it easier for the 4-month-old infants to perceive the stimuli as faces and subsequently use the familiar size of the faces to perceive depth. Another interpretation, however, is possible. The movement might have simply enhanced the infants' attention to the display and thus encouraged a clearer response to the 3-D layout. This possibility could be further examined in the future by presenting faces with salient and not face-specific movement, e.g. flashing.

Though it requires further study to clarify the effect of movement, our results indicate that both 4- and 5-month-old infants' are sensitive to depth information provided by the size of human faces. Yonas et al. (1982) found similar results in 7-month-old infants, but not 5-month-old infants when using reaching as a measure. The finding of younger infants' sensitivity to this pictorial depth cue in the present studies might be related to the use of a methodology that is less demanding than a reaching study. In our study, the infants did not have to estimate whether the distance to the object was within reach or not. Rather, the

infants simply needed to determine which of two objects was nearer—an ability that might develop earlier. If so, the method described in the present study may be particularly useful for examining sensitivity to pictorial depth cues in younger infants.

Our results are consistent with the notion that 4- and 5-month-olds have some sensitivity to depth specified by a pictorial cue. Some previous studies measuring looking behavior in infants younger than 5 months also suggested sensitivity to pictorial depth cues (e.g. Bhatt & Waters, 1998; Shuwairi, Albert & Johnson, 2007), while other studies could not support this finding (e.g. Tsuruhara et al. 2009, 2010). The latter studies might underestimate younger infants' perceptual abilities, with more demanding tasks such as extracting 3-D form information. Our recent study using the method in the present study and another pictorial depth cue supports this interpretation (Tsuruhara, Corrow, Kanazawa, Yamaguchi & Yonas, 2014). In that study, we found different looking behaviors between the monocular and binocular viewing conditions using the height-in-a-picture-plane cue for depth. Infants looked longer at the lower, apparently closer, stimuli under monocular viewing than under binocular viewing conditions. Unfortunately, the methodology used in the present study and Tsuruhara et al. (2014) is limited to testing infants older than 4-months who have been shown to perceive depth from binocular information. However, it would be worthwhile to use this methodology to examine sensitivity to other pictorial depth cues in infants who are too immature to reliably reach, without requiring 3-D form perception which might develop after the ability to judge the difference between 'closer' and 'farther.' Future work should examine the usefulness of this new method in examining the development of other pictorial depth cues.

Furthermore, we would like to emphasize that more work is needed to validate this method as a new and important way to assess depth perception in infants too young to reach. For example, future work could build on the present study by using preferential looking, under monocular and binocular conditions, to look for evidence that the perception of depth from pictorial depth cues is learned from depth information provided by binocular depth cues. In particular, it would be useful to examine if the individual infant develops binocular sensitivity to depth just before pictorial sensitivity.

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Highlights

‘Closer’ preference was compared between monocular and binocular viewings.

Stronger preference in monocular viewing means sensitivity to pictorial depth cues.

Five-month-old infants perceive depth from the size of static human faces.

Smiling motion enhances 4-month-olds’ depth perception from the size of human faces.

Figure 1.

An example of the experimental displays. The surrounding square indicates the frame of the monitor. Note that this example does not include the exact face stimuli presented in the actual experiments because of the models' confidentiality rights. Inverted face pairs, as well as upright ones, were presented in a half of the trials to confirm that the infants' response would be specific to 'faces'. In Experiment 2, a smiling movement was added to the faces; a smiling and back-to-neutral movement was presented repeatedly till the end of each trial.

Figure 2.

Mean preference scores for the larger, apparently 'closer', face for 4- and 5-month-old infants under monocular and binocular viewing conditions in Experiment 1. Scores were calculated by dividing the amount of time infants looked at the larger figure by the total time they looked at either figure (larger or smaller). Error bars indicate standard errors. **: $p < .01$.

Figure 3.

Mean preference scores for the larger, apparently 'closer', moving face for 4-month-old infants under monocular and binocular viewing conditions in Experiment 2. Scores were calculated as in Experiment 1. Error bars indicates standard errors. **: $p < .01$.

Table 1

Mean looking times (s) and standard errors in parentheses.

Age	Viewing	Orientation	trial 1	trial 2	trial 3
Experiment 1	4-months	Monocular	Upright	6.39 (0.51)	6.54 (0.50)
		Inverted	6.00 (0.60)	5.80 (0.52)	5.31 (0.64)
	Binocular	Upright	8.27 (0.55)	8.21 (0.48)	7.52 (0.56)
		Inverted	8.18 (0.42)	6.93 (0.80)	6.93 (0.80)
5-months	Monocular	Upright	7.04 (0.55)	6.12 (0.54)	5.54 (0.40)
		Inverted	5.77 (0.39)	5.85 (0.54)	4.97 (0.51)
	Binocular	Upright	8.13 (0.66)	8.37 (0.50)	7.15 (0.74)
		Inverted	8.09 (0.59)	7.18 (0.59)	7.18 (0.59)
Experiment 2	4-months	Monocular	Upright	7.20 (0.45)	5.96 (0.60)
		Inverted	6.57 (0.58)	5.88 (0.60)	4.88 (0.64)
	Binocular	Upright	8.75 (0.26)	8.85 (0.36)	7.78 (0.36)
		Inverted	9.34 (0.44)	8.46 (0.36)	8.46 (0.36)