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Six-month-old infants perceive the hollow-face illusion

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Abstract

In this study we investigated infants' perception of the hollow-face illusion. 6-month-old infants were shown a concave mask under monocular and binocular viewing conditions and the direction of their reaches toward the mask was recorded. Adults typically perceive a concave mask as convex under monocular conditions but as concave under binocular conditions, depending on viewing distance. Based on previous findings that infants reach preferentially toward the parts of a display that are closest to them, we expected that, if infants perceive the hollow-face illusion as adults do, they would reach to the center of the mask when viewing it monocularly and to the edges when viewing it binocularly. The results were consistent with these predictions. Our findings indicated that the infants perceived the mask as convex when viewing it with one eye and concave when viewing it with two eyes. The results show that 6-month-old infants respond to the hollow-face illusion. Our finding suggests that, early in life, the visual system uses the constraint, or assumption, that faces are convex when interpreting visual input.

1 Introduction

In the hollow-face illusion, observers perceive a concave mask as convex. As Gregory (1970, 1997) has pointed out, this illusion demonstrates that the adult visual system uses constraints, or assumptions, to make inferences about the spatial layout of scenes. Because retinal images are two-dimensional (2-D), three-dimensional (3-D) layout is underdetermined by visual input, and the use of constraints, that faces are convex for example, facilitates perception of 3-D objects and scenes.

The hollow-face illusion is most compelling when a concave mask is viewed with one eye, making binocular cues for the mask's actual shape unavailable (eg Hill and Johnston 2007; Papathomas et al 2010). When a concave mask is perceived as convex, this illusion overpowers conflicting motion-parallax cues: when adult observers move their heads back and forth, optical motion is reinterpreted to maintain consistency with the illusory perception of the mask as convex, and observers report that the mask, which is stationary, rotates to face them as they move (Gregory 1970, 1997). When the mask is viewed with two eyes from a short distance, however, binocular cues indicate the concave structure of the display and the mask is experienced as static and concave.

The constraint that faces are convex may be learned through experience with real convex faces, or it may reflect an evolutionary adaptation. It may apply specifically to faces or reflect a more general assumption that objects and surfaces tend to be convex, rather than concave (eg Hill and Johnston 2007). However, evidence that the hollow-face illusion is specific to faces is provided by Hill and Johnston's report (2007) that the realism of a mask influenced the likelihood that it was perceived as convex. In addition, the effectiveness of the illusion is reduced (but not eliminated) if the mask is inverted, making it less face-like (Hill and Bruce 1993). These results suggest that adults' perception of the illusion might be influenced by both an assumption that faces are convex and a general convexity assumption that is not face-specific.

The goal of the present work was to investigate the nature of these assumptions, specifically if they can be demonstrated early in life. A recent study by Tsuruhara et al (2011) used preferential looking and habituation – dishabituation methods to investigate infants' perception of the hollow-face illusion. They concluded from their results that 7- to 8-month-old infants perceived a rotating concave face portrayed on a computer screen as concave. In other words, they found no evidence that infants at this age perceive the hollow-face illusion and, thus, no evidence that infants' perception of faces is influenced by a convexity assumption.

In the present study we investigated whether 6-month-old infants perceive the hollow-face illusion using a different method: reaching. We hypothesized that infants' reaches toward a concave mask would reveal whether they perceived the mask as concave or convex. Previous studies have found that 5- to 7-month-old infants reach preferentially for the nearest part of an object or surface (eg Kavsek et al 2009; Yonas et al 1978). We, therefore, expected that infants would reach most often for the part of the mask they perceived as nearest to them: the center if the mask were perceived as convex and the edges if it were perceived as concave.

6 month olds were shown a concave mask, which depicted Albert Einstein's face (figure 1), and were allowed to reach for the mask under both monocular (one eye patched) and binocular viewing conditions. Pilot testing with adults found that, at the viewing distances used in our study, the mask was perceived as convex when viewed with one eye and concave when viewed with two eyes. This was consistent with the results from previous studies of the hollow-face illusion (eg Hill and Johnston 2007; Króliczak et al 2006; Papathomas and Bono 2004; Papathomas et al 2010). If infants reach toward the center of the mask under monocular viewing conditions, and toward the edges of the mask under binocular conditions, it would indicate that they, like adults, perceive the concave mask as convex under monocular viewing conditions and concave under binocular conditions.

2 Method

2.1 Participants

Fourteen 6-month-old infants (six males, eight females; mean age = 187 days, age range = 181 – 199 days) were included in the final sample. The majority of infants were of European – American descent. 22 additional infants were excluded from data analyses due to fussiness

(10), failure to reach a minimum of 6 times toward the mask in each of the two conditions (7), experimenter error (1), and equipment error (4). All infants and parents were treated according to the ethical guidelines of the University of Minnesota Institutional Review Board, the American Psychological Association, and the World Medical Association Helsinki Declaration.

2.2 Apparatus and stimuli

The stimulus display was a concave mask of Albert Einstein's face, which was painted on the concave side to increase realism (figure 1). The mask measured 34 cm from the chin to the top of the head and was 10 cm deep (the distance from the frontal plane of the mask to the furthest point of the nose). Therefore, the size of the mask was larger than the average human face. We chose such a large mask so that we would easily be able to distinguish a reach to the center from a reach to the external edges. Two green disks, which resembled earrings, were placed on the sides of the face to provide infants with something to reach for on the mask's edges. The disks were 3 cm in diameter, 1.5 cm thick, and 25 cm apart.

The mask was mounted in a hollow wooden box with its front edge even with the front of the box. The nose of the mask protruded into the interior space of the box away from the infant. The box was 33 cm deep, 96.5 cm wide, and 82.5 cm high. It rested on a table so that the center of the mask was even with the infants' eyes. Infants viewed the face through a 38 cm wide by 39 cm high aperture in the box. A row of LEDs was positioned in front of the mask and illuminated the mask from below. Previous research suggests that lighting a concave mask from below increases the strength of the hollow-face illusion for adults (Hill and Bruce 1993).

Two digital video cameras recorded the infants' reaching behavior toward the display. One was placed to the left of the display (from the infant's perspective), perpendicular to the infant's line of sight. This camera recorded reach behavior from the side. To provide indicators for the location of the mask on the two video recordings, 1 cm high markers were attached to the box between the cameras and the mask. One small marker extended at the level of the top of the mask and another extended at the level of the chin, both on the left vertical wall of the box. The side camera was used to determine where the infants reached along the vertical (Y) axis (eg the forehead, nose, or chin). A second camera was directed downward from the ceiling directly above the mask. Two additional markers were attached on the top (ceiling) of the surrounding box and were aligned on the video recordings with the left and right sides of the face. This camera was used to determine where the infants reached along the horizontal (X) axis (eg the left ear, nose, or right ear). Both camera views could be used to determine the distance of the infants' reaches from the mask along the depth (Z) axis (eg to determine if they stopped their reach short of the mask). By viewing the infant on both recordings, behavior in all three axes of space (X , Y , and Z) could be recorded and the trajectory, or goal, of the reach could be judged.

2.3 Procedure

Infants were placed in an infant seat with four wheels that ran along tracks on a table. On each trial, the seat was pushed along the tracks toward the display to bring the infant within

reaching distance. At the nearest point, the infant's chest was approximately 32 cm from the front of the box. At the furthest point, the infant was approximately 62 cm from the front of the box. Parents either stood behind the infant and pushed the seat forward on each trial or, if they preferred, watched from behind while an experimenter pushed the seat forward on each trial. Parents viewed the display with two eyes before and during the study so that they did not experience the illusion; they were not told the expected response of the infant to minimize their influence on their infants' reaching behavior. On each trial, the infant seat started at the farthest point from the display and was rolled forward on the tracks until the infant was within reaching distance.

There were two conditions in the experiment: A monocular viewing condition, in which the infant wore a patch over one eye, and a binocular viewing condition, in which the display was viewed with both eyes. The order in which the conditions were presented was counterbalanced; half of the infants started the experiment in the monocular condition and half started in the binocular condition.

At the start of each trial, the experimenter drew the infant's attention to the mask by flashing the lights that illuminated the display. If this did not attract the infant's attention, the experimenter tapped on the back of the box. When the infant looked at the display, an experimenter or parent pushed the infant seat toward the display until the infant was within reaching distance. This distance allowed the infant to reach toward the outer portions of the display or toward the center. Each trial ended after the infant reached toward the display; so, only one reach was scored on each trial. If the infant did not reach toward the display within approximately 3 s after arriving at the nearest point to the display, the infant was rolled back to the starting position, and a new trial began. Trials continued, following this procedure, until the infant reached toward the display on a minimum of 6 monocular trials and 6 binocular trials. If the infant was not fussy at the end of the first 6 trials, some additional trials were run before moving onto the next condition. Similarly, if the infant was still not fussy at the end of the second condition, additional trials were run. If an infant became fussy during the experiment, the parent and infant took a break before continuing. In the event that an infant could not be calmed, the experiment was terminated.

To score an infant's reaches, videos were downloaded to a computer and analyzed in slow motion, if needed. A preliminary scorer, blind to the location of the infant's reaches (half of the computer monitor was covered), determined whether an infant should be excluded from the sample based on number of reaches, fussiness, experimenter error, and equipment error. Another scorer was made blind to condition by covering a portion of the computer screen to ensure that it was not possible to see whether or not the infant was wearing an eye patch. This scorer made a forced-choice judgment of whether the infant reached toward the center of the mask or the outer edges (any area other than the center). In other words, the scorers made a judgment, based on the information available, about the goal of the infant's reach. The area scored as the center of the mask constituted approximately 10% of the overall area of the display. If the infant reached with both hands, the experimenter scored the trajectory of the hand that reached first. A scored reach constituted an obvious initiation of hand movement in the direction of the mask. These scored reaches were allowed to extend any distance so long as they approached the mask. In other words, infants were allowed to reach

as far as was physically possible and even touch the display. This allowed for the infant to reach both above and below the mask, to both sides, and into the mask's concave area. For each infant, the percentage of the infant's total reaches that were directed toward the center of the mask was calculated in each condition. This percentage was used as the dependent variable in data analyses. Because the rater made a forced-choice judgment whether reaches were directed to the center or edges of the mask, percentage of reaches to the center and percentage of reaches to the edges summed to 100% for every infant. A third experimenter scored the videos to determine inter-judge reliability. A strong correlation between the percentages judged by the two scores was found ($r = 0.94$, $n = 28$).

3 Results

A preliminary analysis found no effects of gender and no effect of condition order. Thus, the data from these groups were combined for subsequent analyses.

For each infant, the percentage of total reaches that were directed toward the center of the mask were computed in each viewing condition. The mean percentage of reaches to the center was 68% (SD = 31.2%) in the monocular condition, and 25% (SD = 30%) in the binocular condition. A paired-samples t -test revealed a significant difference between these means ($t_{13} = 4.42$, $p = 0.001$), with a large effect size, Cohen's $d = 1.199$. This result indicates that the infants reached significantly more often to the center region of the mask in the monocular trials than in the binocular trials. In addition, we conducted planned one-sample t -tests, which compared the means in each condition to 50%. Because the reaches were scored in a binary fashion, we chose 50% as a test value. However, this test value was quite conservative because the area of the mask that was scored as a reach to the center constituted only about 10% of the total mask, rather than 50% of the area of the mask. We found that the infants reached toward the center of the display significantly more often than 50% in the monocular viewing condition ($t_{13} = 2.20$, $p = 0.047$), and significantly less often than 50% in the binocular condition ($t_{13} = -3.04$, $p = 0.009$). Overall, these results suggest that infants perceived the mask as convex in the monocular condition and concave in the binocular condition.

One possible alternative interpretation of the data is that infants perceived the mask as flat in the monocular condition. This is unlikely for two reasons. First, if infants perceived the mask as flat, they would have reached uniformly over the area of the display rather than reaching to the center. The data show that this was not the case. Although the center area occupied about 10% of the overall area of the mask, infants reached to that area in approximately 68% of the monocular trials. Second, there were multiple occasions in which the infants stopped their reaches short of the front surface of the mask and closed their fingers in the air, as if attempting to grasp the nose protruding toward them. This behavior was observed in eleven of the fourteen infants (41 total trials) in the monocular condition and in only four infants (12 trials) in the binocular condition.

One potential concern regarding this sample was the high attrition rate. Although it is typical for infant studies using reaching methods to have substantial attrition rates (eg Yonas et al 1978), our attrition rate was very high. Many infants were not interested enough in the static

mask to reach for it, some may have been distressed because their parent was out-of-sight behind them, and others may have been distracted by the eye patch. To ensure that the loss of these participants did not affect the outcome of the study, we examined the data from infants who produced at least one reach to see if the reaches that they did produce were consistent with our general findings. Of the infants excluded for reasons including fussiness, failure to reach, or one missing video due to equipment error, eight exhibited at least one reach during the experiment (with an average of 5.4 reaches in the monocular condition and 7.4 in the binocular condition). These infants reached to the center of the mask on 61% of the monocular trials and on 29% of the binocular trials. These results are consistent with the data from infants who completed the experiment and suggest that the attrition of these infants did not have an effect on the results of the study.

4 Discussion

The results demonstrate that 6-month-old infants perceive the hollow-face illusion. Since infants at this age reach to the nearest parts of objects and surfaces, the infants' reaching preference for the center of the mask in the monocular condition indicates that they, like adults, perceived the mask as convex, most of the time, when viewing it with one eye. Furthermore, their reaching preference for the edges of the mask in the binocular condition indicates that they perceived the mask as concave when viewing it with two eyes. Overall, the results suggest that 6-month-old infants and adults perceive the hollow-face illusion in a similar fashion. This is interesting for several reasons. Infants consistently responded to the illusion even if they were presented with the binocular condition first and even though they were allowed to touch the mask on each trial. In other words, they had extensive information available to them indicating the concave nature of the display, yet still reached to the center on monocular trials. This is consistent with adults' reports of seeing the illusion despite knowing that the mask is concave. In addition, we used a larger than average display to make it easier to score the location of the infants' reaches. By doing so, we increased the amount of horizontal stereo disparity available to the infants in the binocular condition, lessening the chance that they could see the illusion in the binocular condition. This information could have carried-over to the monocular condition. Nonetheless, infants still responded to the illusion.

The hollow-face illusion illustrates the visual system's use of constraints to interpret visual input. Because retinal images are 2-D, they provide ambiguous information about the 3-D world, and the recovery of 3-D structure is underdetermined by optics. The adult visual system disambiguates retinal-image information by using constraints that exploit regularities in the world. For example, shading information for shape is disambiguated by assuming that light comes from a single direction, that lighting intensity and reflectance are uniform across a surface, and that light comes from above (Barrow and Tenenbaum 1978). In addition, objects' distances are disambiguated by assuming that objects rest on the ground (Bian et al 2005; Gibson 1950). These constraints limit the possible interpretations of retinal-image information and make perception of the 3-D world possible. Although the constraint that faces are convex can result in an illusion that a concave mask is convex, under some conditions it probably facilitates accurate perception in real-world situations by helping the visual system overcome ambiguous retinal-image information (Gregory 1997). The results

of the present study, together with previous research, indicate that the infant visual system uses the light-comes-from-above constraint to perceive shape from shading (Granrud et al 1985) and the constraint that faces are convex, or that objects in general tend to be convex, to recover the 3-D structure of a face.

Gregory (1997) describes perception as a problem-solving process and explains several illusions by referring to the use of assumptions and an inferential process to arrive at a percept. His view, applied to this experiment, explains the perception of a concave mask as convex as resulting from an assumption that faces are convex. When the concave mask is viewed with one eye, adults and infants make an inference based on that assumption and come to the unconscious conclusion that the face is convex. Gregory is correct in his claim that conscious cognitions play no role in the experience of the mask as convex. In adults, perception of the hollow-face illusion is unaffected by explicit knowledge about the mask's actual shape. Instead of explicit knowledge, the constraint that faces are convex, and the resulting perception that a concave mask is convex, results from unconscious processes.

Gregory's theory provides a useful metaphor for understanding perception. However, it does not provide a satisfying explanation of how neural circuitry in the brain uses constraints to pick up 3-D information for shape, such as the convex shape of a face. Understanding how the brain uses constraints and retinal input to perceive a concave mask as convex is an important goal for future work. An account of this process should address the processes underlying two facts. First, that binocular information for the concave structure of the mask can overcome the illusion. And second, that when the mask is viewed with one eye from adequately long distances, motion of the viewer makes the face appear to move in a way that is consistent with the perception of the mask as convex.

One approach to answering these questions would be to analyze the problem from a Bayesian perspective. Infants' reaches to the center of the mask in the monocular condition suggest the existence of a prior that either faces are convex or that things, in general, tend to be convex. The source of this prior, however, is still up for debate. It is possible that, as a result of evolutionary history, infants have an innate tendency to see faces and objects as convex. Yet, it remains unclear whether infants younger than 6 months of age perceive the hollow-face illusion.

Although reaching methods are useful for studying depth perception in infants 5 months of age and older (eg Kavsek et al 2009), other methods will be needed to study younger infants who do not yet reach for objects. Although Tsuruhara et al (2011) found no evidence that 7–8-month-old infants perceive the hollow-face illusion using preferentially looking and habituation – dishabituation methods, these methods may, nevertheless, be useful for studying young infants' perception of this illusion. The approach used in the present study, comparing reaching behavior under binocular and monocular viewing conditions, could potentially be adapted to preferential looking methods to investigate perception of this illusion in infants who are too young to reach. If infants perceive the hollow-face illusion under monocular viewing conditions, and prefer to look at the closest part of a display, the gaze of the infant should be directed to the center more frequently in a monocular than in a binocular viewing condition.

Future research will also be needed to determine whether, in infancy, the constraint that faces are convex is specific to faces or whether it is part of a more general constraint that objects are usually convex. Research with adults has revealed that face-specific processes are involved in the perception of the illusion. The hollow-face illusion is more compelling with upright rather than inverted faces (Hill and Bruce 1993) and with realistically painted masks than with less realistic masks (Hill and Johnston 2007; Papatomas et al 2010). A question for future research is whether these effects can be found in young infants, or whether infants' perception of the hollow-face illusion is based on a general convexity assumption, with face-specific effects developing later.

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References

- Barrow, HG.; Tenenbaum, JM. Recovering intrinsic scene characteristics from images. In: Hanson, AR.; Riseman, EM., editors. *Computer Vision Systems*. New York: Academic Press; 1978. p. 3-26.
- Bian Z, Braunstein ML, Anderson GJ. The ground dominance effect in the perception of 3-D layout. *Attention, Perception, & Psychophysics*. 2005; 67:802–815.
- Gibson, JJ. *The Perception of the Visual World*. Oxford: Houghton Mifflin; 1950.
- Granrud CE, Yonas A, Opland EA. Infants' sensitivity to the depth cue of shading. *Perception & Psychophysics*. 1985; 37:415–419. [PubMed: 4047903]
- Gregory, RL. *The Intelligent Eye*. New York: McGraw-Hill; 1970.
- Gregory RL. Knowledge in perception and illusion. *Philosophical Transactions of the Royal Society of London*. 1997; 352:1121–1128. [PubMed: 9304679]
- Hill H, Bruce V. Independent effects of lighting, orientation, and stereopsis on the hollow-face illusion. *Perception*. 1993; 22:887–897. [PubMed: 8190593]
- Hill H, Johnston A. The hollow-face illusion: Object-specific knowledge, general assumptions or properties of the stimulus? *Perception*. 2007; 36:199–223. [PubMed: 17402664]
- Kavsek M, Granrud CE, Yonas A. Infants' responsiveness to pictorial depth cues in preferential-reaching studies: A meta-analysis. *Infant Behavior and Development*. 2009; 32:245–253. [PubMed: 19328557]
- Króliczak G, Heard P, Goodale MA, Gregory RL. Dissociation of perception and action unmasked by the hollow-face illusion. *Brain Research*. 2006; 1080:9–16. [PubMed: 16516866]
- Papatomas TV, Bono LM. Experiments with a hollow mask and a reverspective: Top-down influences in the inversion effect for 3-D stimuli. *Perception*. 2004; 33:1129–1138. [PubMed: 15560511]
- Papatomas TV, Marks M, Silverstein SM, Keane BP, Sinha P, Pavlovic V. The role of pictorial cues in the hollow-face illusion: Binocular disparity versus motion parallax. *Perception*. 2010; 39(Supplement):107.
- Tsuruhara A, Nakato E, Otsuka Y, Kanazawa S, Yamaguchi M, Hill H. The hollow-face illusion in infancy: do infants see a screen based rotating hollow mask as hollow? *i-Perception*. 2011; 2:418–427. [PubMed: 23145235]
- Yonas A, Cleaves W, Pettersen L. Development of sensitivity to pictorial depth. *Science*. 1978; 22:77–79. [PubMed: 635576]

Figure 1.

Image of the stimulus display. Although the mask is concave, with its nose pointing away from the observer, adult observers report a compelling illusion that the mask is convex and that its nose points toward them when it is viewed with one eye. Note that, in this photograph, the viewer will perceive the mask as convex when viewing it with two eyes, because binocular information for the concave shape of the mask is absent.