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Illusory Contour Figures Are Perceived as Occluding Contours by 4-Month-Old Infants

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Although 4-month-olds perceive continuity of an object's trajectory through occlusion, little is known about the information specifying an occluding surface at this age. We investigated this in 3 experiments involving 84 participants. Testing the claim that 5-month-olds are unable to perceive the Kanizsa figure as an occluding surface (Csibra, 2001), we demonstrated that 4-month-olds perceived trajectory continuity behind this figure providing its horizontal extent was small. We demonstrated that the presence of visible occluding edges or occlusion of background was insufficient to specify an occluding surface but that their combination was sufficient. Thus, beyond object deletion and accretion, both visible occluding edges and occlusion of background are necessary for perception of occluding surfaces at this age.

Keywords: illusory contours, occlusion, infant perception, object trajectory, object persistence

The ability to detect the persistence of objects as they pass behind occluding surfaces is a fundamental of human perception, and there is now evidence that this capacity is present early in infancy. Figure 1 illustrates one method of testing infants' perception of trajectory continuity. Infants are habituated to a display in which an object moves back and forth across a display screen, disappearing behind a centrally placed occluder (see Figure 1A), and looking preference is assessed on two test trials in which the occluder is absent but the object moves either discontinuously (see Figure 1B) or continuously (see Figure 1C). The rationale is that if infants perceive continuity in the habituation trajectory, they should exhibit a novelty preference for the discontinuous test display, whereas if they perceive discontinuity, they should show a novelty preference for the continuous test display. The period around 4 months of age appears to be pivotal for the emergence of perception of trajectory continuity. Two-month-olds do not perceive an object's trajectory as continuous even across the shortest gap in perception, whereas 6-month-olds exhibit robust perception of trajectory continuity (Johnson et al., 2003). Four-month-olds are the youngest infants to have been shown to perceive trajectory continuity, and they only do so when the occlusion event is of short duration or takes place across a short spatial extent (Bremner et al., 2005; Johnson et al., 2003).

Perception of the continuity of an object trajectory involves perceiving an occluding surface consistent with the temporary disappearance of the object. However, relatively little is currently known regarding what specifies an occluding surface for young infants. To reach a full understanding of the extent of the emergent ability and to identify likely further developments in the months that follow, it is particularly important to discover the cues that infants are capable of using at the point of emergence of perception of trajectory continuity at around 4 months of age.

Perception of the continuity of a moving object despite its deletion and accretion at occluder boundaries, known as the *tunnel effect* (Burke, 1952), is apparent in adults even when there is no visible occluding surface (Kahneman, Triesman, & Gibbs, 1992; Michotte, Thines, & Crabbe, 1964/1991). On seeing an object that is deleted and accreted at the edges of an invisible occluder, adults perceive it as disappearing into and reappearing from a slit or tunnel in the background; thus, deletion and accretion appear to be sufficient information to specify an occluding surface. It would appear that young infants are not subject to the tunnel effect: Following habituation to a deletion and accretion event with a visible occluder, 4- and 6-month-olds often look longer at a deletion and accretion event without a visible occluder in comparison to an event involving a continuous trajectory without an occluder, presumably because of a preference for novelty (Bremner et al., 2005, Bremner et al., 2007; Johnson et al., 2003; see Figure 1). If deletion and accretion by themselves specified an occluding surface for young infants, one would predict either a null result or a

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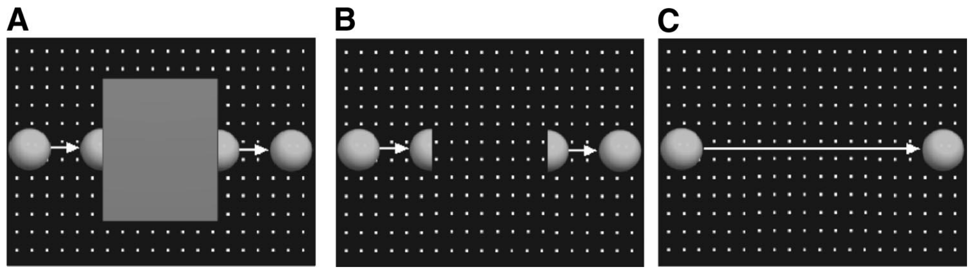

Figure 1. Displays used in past research to investigate infant perception of trajectory continuity. A: Habituation display. B: Discontinuous test display. C: Continuous test display.

preference for the continuous trajectory, as it was more different from either of the two deletion and accretion events.

If deletion and accretion alone, that is, in the absence of a visible occluder, are not sufficient to support young infants' perception of object persistence through occlusion, it is relevant to ask what other information must be provided for infants to perceive an occlusion event as such. The clearest information specifying an occlusion event is the presence of a luminance-defined bounded surface that has edges coinciding with deletion and accretion events; work on trajectory perception confirms that provision of this information is sufficient even in computer-generated displays containing minimal explicit depth information (Bremner et al., 2005, 2007; Johnson et al., 2003). This leads to the question of whether less direct specification of an occluder may be sufficient, in combination with deletion and accretion, to specify an occlusion event.

Here, there are already some pointers in the literature. In the case of the Kanizsa figure, adults perceive a strong illusion of a rectangular surface, closer in depth than the inducing elements, and this led Kanizsa (1979) to conclude that the rectangle was perceived as an occluding surface. We know that infants at 7 months (Bertenthal, Campos, & Haith, 1980) and perhaps even 3 months (Ghim, 1990) perceive the illusory contours presented by static Kanizsa figures and that 3- to 4-month-olds demonstrate detection more robustly when the illusory figure is in motion (Kavšek & Yonas, 2006; Otsuka & Yamaguchi, 2003; Yoshino, Idesawa, Kanazawa, & Yamaguchi, 2010). Furthermore, Csibra (2001) demonstrated that 8-month-olds, but not 5-month-olds, perceive illusory contour figures as occluding surfaces. This is a key finding with respect to the focus of the present article because it demonstrates a condition in which information short of a visible surface with luminance-defined boundaries leads 7-month-olds to perceive object deletion and accretion as though behind an occluding surface.

However, given what is known about young infants' sensitivity to time and distance out of sight in moving object occlusion events (Bremner et al., 2005; Johnson et al., 2003), we should consider the possibility that this ability may be present considerably earlier than 8 months of age. The Csibra (2001) task involved test events in which a moving object was deleted and accreted at boundaries that were either aligned or unaligned with an illusory Kanizsa square (see Figure 2), the question being whether infants looked longer at the unaligned occlusion event. The elegant design led to familiarization and test displays containing six "pacman" elements, with the position of the illusory contour determined by different rotations of the elements. Csibra used an optimal speed for detection of trajectory continuity by young infants (Bremner et al., 2005), and the combination of object speed and illusory occluder width resulted in occlusion times and distances within the range of values that lead to perception of continuity by 4-month-olds viewing a fully visible occluder (Johnson et al., 2003). However, these occlusion times and distances present conditions that are near the limit of a 4-month-old's ability to fill in gaps in perception in this sort of task and thus might present a sufficiently high perceptual load to prevent perception of trajectory continuity when the occluder was illusory. It is possible that the cumulative load involved in perceiving the illusory surface and filling in the spatiotemporal gap was beyond the younger infants' processing capacity. In short, infants may only be able to identify a moving object occlusion event as such when they are able to integrate information about deletion and accretion with information specifying an occluding surface, and it is possible that young infants are only capable of this when this dual perceptual load is low enough to be within their processing capacity. Thus, as the starting point of our investigation of the conditions under which infants perceive continuity of an object's trajectory, in Experiment 1, we carried out an investigation of 4-month-olds' ability to perceive the Kanizsa figure as an occluding contour. We followed this in Experiments 2 and 3 with systematic manipulations to assess the effects of occlusion of background and visibility of an edge as cues to an occluding surface. In all three experiments, we focused on investigating 4-month-olds' performance, with the aim of establishing the parameters determining the emergent ability to perceive trajectory continuity across occlusion.

Experiment 1

In Experiment 1, we adopted the method used previously to investigate young infants' perception of trajectory continuity (Bremner et al., 2005, 2007; Johnson et al., 2003), replacing the visible occluding surface with a Kanizsa illusory surface. Additionally, we compared different widths of illusory occluder, predicting that young infants would perceive an object occlusion event when the occluding surface was narrow but not when it was of a width that achieved the same time out of sight as in the Csibra (2001) investigation.

Method

Participants. Forty-eight 4-month-old infants (M = 128.2 days; range = 111–154 days; 25 girls and 21 boys) took part in the

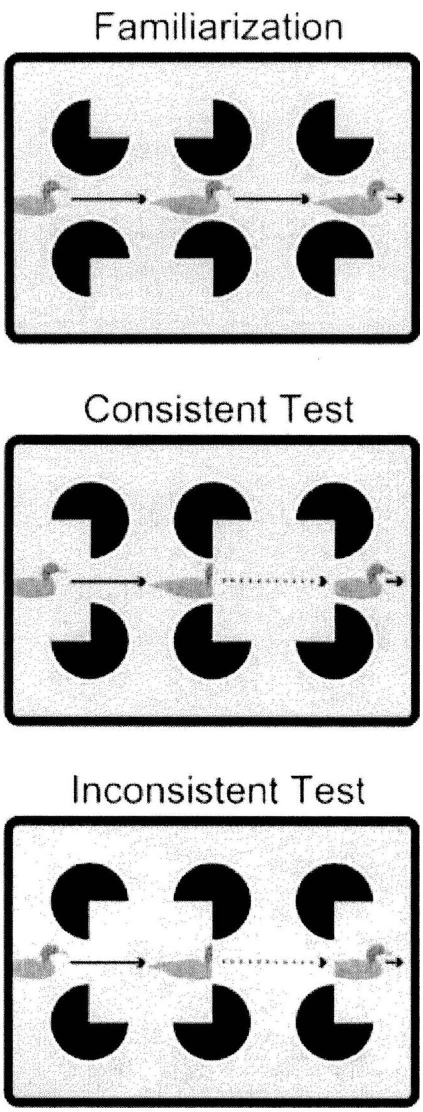

Figure 2. The display presented in Csibra (2001). From "Illusory Contour Figures Are Perceived as Occluding Surfaces by 8-Month-Old Infants" by G. Csibra, 2001, *Developmental Science, 4,* p. F8. Copyright 2001 by Wiley.

experiment. A further four did not complete testing because of fussiness. Twelve infants were assigned to each of the four experimental and control conditions in such a way as to ensure that the mean age and the gender balance were comparable across conditions. Throughout the series, infants took part in only one experiment. In all experiments, participants were recruited by personal contact with parents in the maternity unit when the baby was born, which was followed up when the infants were near test age by telephone contact with those parents who volunteered to take part. Infants with reported health problems, including visual and hearing deficits and those born two weeks or more before their due date, were omitted from the sample. The majority were from Caucasian, middle-class families.

Apparatus and stimuli. A Macintosh computer and a Samsung 100-cm color monitor were used to present stimuli and collect looking-time data. An observer viewed the infant on a second monitor, and infants were video recorded for later independent coding of looking times by a second observer. Both observers were unaware of the hypothesis under investigation. Using Habit software (Cohen, Atkinson, & Chaput, 2000), the computer presented displays, recorded looking-time judgments, calculated the habituation criterion for each infant, and changed displays after the criterion was met. The observer's judgments were input with a keypress on the computer keyboard.

Figure 3 indicates the displays used in this experiment. The habituation display was presented against a black background with a 20 × 20 grid of white dots measuring 48 × 48 cm (27° × 27°) serving as texture elements. Four Kanizsa figure-inducing pacman elements 6.7 cm in diameter were presented with vertical separation of 15 cm and horizontal separation of 7.7 cm (4.4° visual angle; narrow occluder condition) or 10.4 cm (5.9°; wide occluder condition) center to center. A 6.7-cm (3.8°) green ball moved back and forth from one side of the display to the other, moving at 16.5 cm/s (9.4°/s) and undergoing deletion at an invisible vertical edge aligned with one pair of inducing elements and accretion at an invisible edge aligned to the other pair of inducing elements. It took 2,520 ms for the ball to traverse the width of the display. Time from complete visibility to invisibility or the reverse was 360 ms. Time totally out of sight was 80 ms (narrow occluder) or 240 ms (wide occluder). Time completely in sight to the left and right of the occluder was 1,720 ms (narrow occluder) or 1,560 ms (wide occluder). The animation was run as a continuous loop for the duration of the trial. In test displays, the inducing elements were removed and the ball moved back and forth at the same speed as in

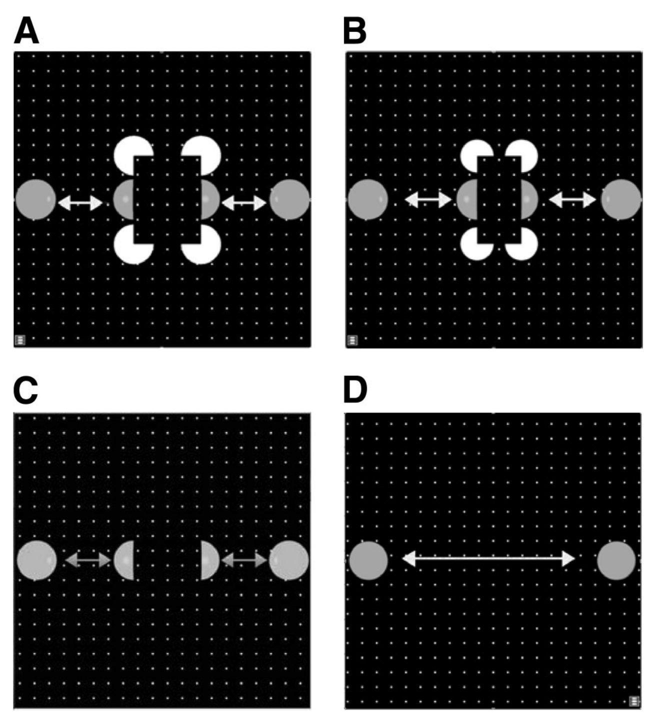

Figure 3. Displays presented in Experiment 1. A: Wide occluder habituation display. B: Narrow occluder habituation display. C: Wide occluder discontinuous test display. D: Wide occluder continuous test display.

the habituation display. In the continuous trajectory test display, the ball was always visible. In the discontinuous trajectory display, the ball went out of and back into view just as in the habituation event.

Procedure. Each infant was seated 100 cm from the display and tested individually in a darkened room. For infants in the experimental condition, the habituation display was presented until looking time declined across four consecutive trials, from the second trial on, adding up to less than half of the total looking time during the first four trials. Timing of each trial began when the infant fixated the screen after display onset. The observer pressed a key as long as the infant fixated the screen and released the key when the infant looked away. A trial was terminated when the observer released the key for 2 s or 60 s had elapsed. Between trials, a beeping target was shown to attract infants' attention back to the screen. After habituation trials, infants were presented with the two test trials in alternation, three times each, for a total of six trials. Infants in the control conditions received only the test trials to assess any intrinsic preference. On test trials, half of the infants in each condition were presented with the continuous trajectory first, and the rest viewed the discontinuous trajectory first. The second observer coded looking times from videotape for purposes of assessing reliability of looking-time judgments. Interobserver correlations were high across the three experiments in this report ($r = .98$).

Results

Figure 4 shows looking times at the two test displays. Infants in the control conditions looked approximately equally at the two displays. In the experimental conditions, infants looked longer at the discontinuous test trial, although this difference was small in the case of the wide occluder display. We can have confidence in assuming that longer looking at one test display is indicative of a novelty preference rather than a familiarity preference for two reasons. First, infants were habituated to a standard criterion, circumstances under which familiarity preferences rarely occur. Second, several articles have reported systematic age-related data that would be very hard to interpret on the basis of familiarity preference, and the same applies in the present series of experiments. A 2 (display: wide vs. narrow) × 2 (condition: experimental vs. control) × 2 (test trial order) × 2 (test trial type: continuous vs. discontinuous) × 3 (test trial block) mixed analysis of variance (ANOVA) yielded a significant effect of test trial type, $F(1, 38) = 10.85$, $p = .002$, $\eta_p^2 = .22$. This was qualified by a significant interaction between test trial type and condition, $F(1, 38) = 11.05$, $p = .002$, $\eta_p^2 = .22$, and thus further analyses were carried out on experimental and control conditions separately. In the experimental conditions, there was a significant effect of test trial type, $F(1, 20) = 17.95$, $p = .001$, $\eta_p^2 = .47$, qualified by an interaction between test trial type and display that approached significance, $F(1, 20) = 4.18$, $p = .054$, $\eta_p^2 = .17$. Infants exposed to the narrow occluder displays looked significantly longer at the discontinuous test trial ($M = 22.84$, $SD = 12.81$) than the continuous tests trial ($M = 11.07$, $SD = 5.36$), $F(1, 10) = 21.4$, $p = .001$, $\eta_p^2 = .68$, whereas infants exposed to the wide occluder displays showed no significant difference in looking between the test displays (discontinuous test $M = 21.19$, $SD = 14.22$; continuous test $M = 16.07$, $SD = 7.85$), $F(1, 10) = 2.23$, $p = .16$, $\eta_p^2 = .18$. In the control conditions, there was no effect of test trial type (discontinuous test $M = 25.82$, $SD = 13.05$; continuous test $M = 26.04$, $SD = 14.32$), $F(1, 20) = 0.008$, $p = .93$, $\eta_p^2 = .00$. There was, however, a significant effect of test trial block (Block 1 $M = 32.72$, $SD = 20.13$; Block 2 $M = 24.93$, $SD = 20.13$; Block 3 $M = 20.15$, $SD = 18.19$), $F(2, 19) = 4.61$, $p = .023$, $\eta_p^2 = .33$, and a significant interaction between test trial type and test trial order, $F(1, 20) = 8.68$ $p = .008$, $\eta_p^2 = .30$. These effects can be interpreted in terms of a reduction in looking across test trials.

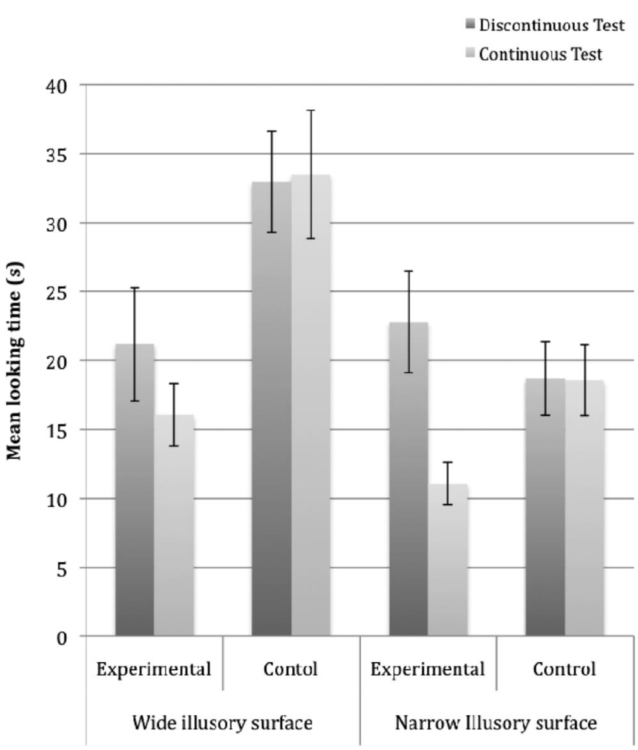

Figure 4. Mean looking times to the two test displays for wide and narrow illusory occluder conditions in Experiment 1. Error bars display standard errors.

Discussion

Infants exposed to the object occlusion event involving the narrow illusory occluder perceived trajectory continuity, whereas those exposed to the wide illusory occluder event showed no evidence of doing so. Although this group showed a trend in the same direction as those exposed to the narrow occluder event, this was not a significant effect, and the near-significant interaction between test trial type and display suggests that the two groups performed differently. These results confirm our prediction that young infants would perceive trajectory continuity in an event in which the object appeared to pass behind an illusory Kanizsa occluder, provided that the spatiotemporal gap in perception was small. In contrast with the Csibra (2001) conclusion that the ability to treat a Kanizsa figure as an occluding surface emerges sometime between 5 and 8 months of age, our results suggest that the ability is present at 4 months. In other words, the Kanizsa figure is effective at the earliest point in development at which infants demonstrably perceive trajectory continuity behind an occluding surface.

Experiment 2

The result with the narrow illusory occluder in Experiment 1 is striking. The Kanizsa figure neither occludes background nor presents visible, luminance-defined edges in the region that the ball travels across. Yet 4-month-olds apparently treated it as a continuous occluding surface in the same way as they do a fully visible luminance-defined surface (Bremner et al., 2005; Johnson et al., 2003). This raises the question of whether Kanizsa-type illusory figures present a special case or whether other information short of a visible surface would be sufficient information to specify an occluding surface. A visible surface both presents luminance-defined occluding edges and occludes background. The favored interpretation of the Kanizsa illusion is that it is perceived as a surface nearer in depth and partially occluding four discs. Thus, locally, this figure presents both occlusion of background (the discs) and visible occluding edges in the region of the inducing elements. Notably, however, neither of these cues is present in the region of the object's trajectory in Experiment 1. To test whether either of these cues on their own would be sufficient information for an occluding surface when presented globally, particularly along the line of the object's trajectory, in Experiment 2, we habituated infants to a moving object occlusion event in which either a thin edge specified the surface but there was no occlusion of background or no edge was visible but background was occluded (see Figure 5; the use of the dot texture background allowed the latter manipulation). In these conditions, we further reduced the occluder width to minimize the perceptual load associated with interpolating across the spatiotemporal gap in perception.

Method

Participants. Twenty-four 4-month-old infants (M = 121.9 days; range = 107–145 days; 12 girls and 12 boys) took part in the experiment. Twelve infants were assigned to each of the two conditions in such a way as to ensure that the mean age and gender balance were comparable across conditions.

Apparatus and stimuli. The same apparatus as in Experiment 1 was used for stimulus presentation, video recording of the infant, and recording looking times. The habituation display was presented against a black background with a 20 × 20 grid of white dots measuring 48 × 48 cm (27° × 27°) serving as texture elements. The thin-edge display included a centrally placed outline rectangle with vertical and horizontal dimensions 15 cm (8.58°) and 7 cm (4°). The background-occluding display contained no visible edge, but the background grid was omitted within the 15- × 7-cm rectangle. A 6.7-cm (3.8°) green ball moved back and forth from one side of the display to the other, undergoing deletion and accretion at the vertical thin edges or the corresponding positions in the occlusion condition. In both conditions, time out of sight was 40 ms and time completely in sight to the left and right of the occluder was 1,760 ms. The animation was run as a continuous loop for the duration of the trial. Test displays contained no visible edges or background occlusion and the ball moved back and forth at the same speed as in the habituation display. In the continuous trajectory test display, the ball was always visible. In the discontinuous trajectory display, the ball went out of and back into view just as in the habituation event.

Procedure. Infants were first habituated to the thin edge or background occlusion event and then were presented with the two test displays in alternation, three times each, for a total of six test trials. On test trials, half of the infants in each condition were presented with the continuous trajectory first, and the rest viewed the discontinuous trajectory first. Habituation and test trials were carried out according to the same criteria and procedures as in Experiment 1. Because the test displays were similar to those used in Experiment 1 and in previous work (Bremner et al., 2005; Johnson et al., 2003) in which, without exception, null preferences were obtained in control conditions, we did not include control conditions in this or the subsequent experiment.

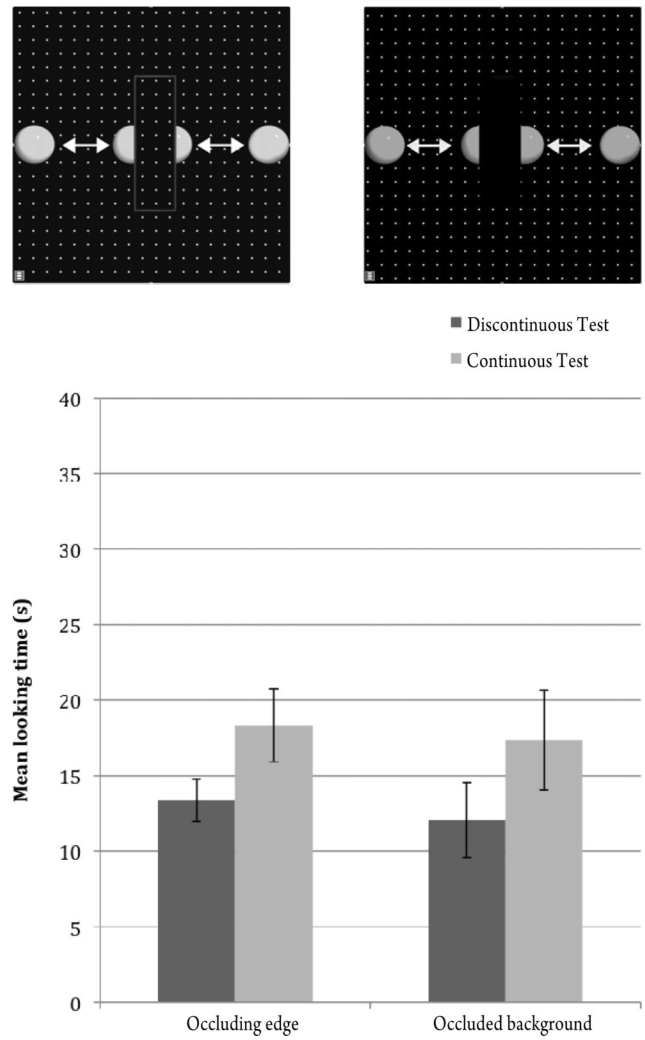

Figure 5. The habituation displays and mean looking times to the two test displays in the thin edge and background occlusion conditions of Experiment 2. Error bars display standard errors.

Results and Discussion

As Figure 5 indicates, infants exposed to the thin line or background occlusion habituation displays looked longer at the continuous test trial (M = 17.85, SD = 9.8) than at the discontinuous test trial (M = 12.71, SD = 6.8). A 2 (display: thin edge vs. background occlusion) × 2 (test trial order) × 2 (test trial type:

continuous vs. discontinuous) × 3 (test trial block) mixed ANOVA yielded a significant effect of test trial type, $F(1, 20) = 5.32$, $p = .03$, $\eta_p^2 = .21$, infants looking significantly longer at the continuous test display. There was no significant interaction between test trial type and display.

The fact that infants in both conditions looked longer at the continuous test display indicates that they perceived the habituation event as an object moving on a discontinuous trajectory. Thus, it appears that neither a thin occluding edge nor occlusion of background texture is sufficient information to specify an occluding surface. It would appear that in the absence of adequate information for an occluding surface, the occlusion event specified discontinuity of the object's trajectory.

Experiment 3

The very different outcome of Experiment 2 compared with that in the narrow illusory occluder condition of Experiment 1 attests to the strength of the illusory surface effect even at 4 months. In our final experiment, we posed the question of whether, apart from the illusory surface condition, there are conditions short of the presence of a luminance-defined surface that are sufficient to specify an occluding surface for 4-month-olds. Specifically, would combining the cues presented separately in Experiment 2 cross a threshold to specify an occluding surface?

Method

Participants. Twelve 4-month-old infants ($M = 124.1$ days; range = 115–131 days; six girls and six boys) took part in the experiment. A further two did not complete testing because of fussiness.

Apparatus, stimuli, and procedure. The same apparatus as in Experiment 1 was used for stimulus presentation, video recording of the infant, and recording looking times. The habituation display was a combination of the displays presented in Experiment 2, combining both a centrally placed outline rectangle with background texture occlusion within this outline (see Figure 6). A 6.7-cm (3.8°) green ball moved back and forth at the same speed as in Experiments 2 and 3. In all other respects, the procedure was identical to that in Experiment 2.

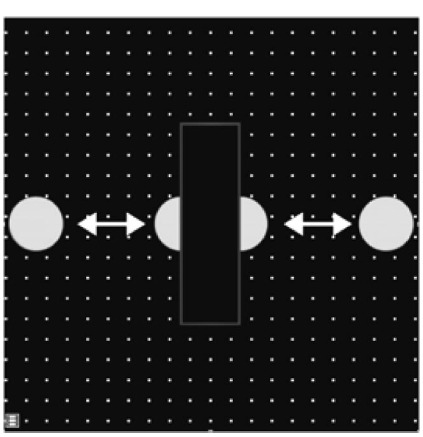

Figure 6. The habituation display used in Experiment 3.

Results and Discussion

Following habituation to the thin line and background occlusion display, infants looked longer at the discontinuous test display ($M = 24.29$, $SD = 11.23$) than at the continuous test display ($M = 16.96$, $SD = 10.68$). A 2 (test trial order) × 2 (test trial type: continuous vs. discontinuous) × 3 (test trial block) mixed ANOVA confirmed significantly longer looking at the discontinuous test display, $F(1, 10) = 8.92$, $p = .014$, $\eta_p^2 = .47$, indicating that they perceived trajectory continuity in the case of this display. To compare the results with those of Experiment 2, we carried out a 3 (display: thin edge vs. background occlusion vs. thin edge and background occlusion) × 2 (test trial order) × 2 (test trial type: continuous vs. discontinuous) × 3 (test trial block) mixed ANOVA on the data set for both experiments. This indicated no overall significant effect of test trial type, $F(1, 30) = 0.34$, $p = .57$, $\eta_p^2 = .01$. However, there was a significant interaction between test trial type and display, $F(2, 30) = 6.06$, $p = .006$, $\eta_p^2 = .29$, arising from the opposite results obtained in the two experiments.

The contrasting result in this experiment compared with Experiment 2 indicates that although the presence of a luminance-defined occluding edge or background texture occlusion were singly insufficient to specify an occluding surface, their combination was sufficient to do so. This led infants to perceive the moving object occlusion event as a continuous movement of an object passing behind an occluder.

General Discussion

Experiment 1 demonstrated that 4-month-olds see the Kanizsa figure as an occluding surface, perceiving a moving object's trajectory as continuous across an occlusion event involving this illusory surface. Furthermore, as with their perception of visible occluding surfaces, their perception of continuity is limited to short occlusions. Experiment 2 demonstrated that neither a visible occluding edge nor background occlusion was sufficient on its own to support perception of an occluding surface, but Experiment 3 demonstrated that these two cues in combination did specify an occluder. Our conclusion is that in addition to deletion and accretion of the moving object, the presence of both background occlusion and visible occluding edges is necessary to specify an occluding surface for 4-month-olds. However, given that the Kanizsa figure only provides these cues in the regions of the inducing elements, explicit information does not have to exist in the path of the object, other than accretion and deletion at the illusory edges. Given that this information is apparently insufficient on its own to specify an occluding surface for 4-month-olds and was present in Experiments 2 and 3, it is clear that it was the Kanizsa figure that provided the extra information to specify an occluding surface.

The null result in Experiment 1 with the wider illusory occluder is generally in accord with our previous findings that 4-month-olds only perceive trajectory continuity when the time or distance out of sight is short (Bremner et al., 2005; Johnson et al., 2003). However, the wide occluder was still narrower than one of the occluder widths yielding positive results with a visible occluding surface (Johnson et al., 2003). Our hypothesis was that this null result could be expected because the processing load involved in the combined process of perceiving the illusory occluder and filling in the perceptual gap across occlusion was beyond young infants' processing capacity.

There is already a way to operationalize processing load for illusory figures. Shipley and Kellman (1992) defined *support ratio* in Kanizsa figures as the ratio of contour in the inducing elements to total contour in the illusory surface and identified this as an important factor in perception of the illusion. Otsuka, Kanazawa, and Yamaguchi (2004) demonstrated that 3- to 4-month-olds only perceive the Kanizsa illusion when there is a relatively high support ratio. Specifically, they obtained evidence for perception of the illusory contour when the support ratio was .66 but not when it was .37. The support ratio in our narrow illusory figure was .59, whereas it was .53 for the wide illusory occluder. Although these ratios are not very different, the ratio for the wide occluder was precisely halfway between the ratios used by Otsuka et al. (2004), and it is possible that it lies below the threshold for perception of an illusory surface. However, this would not explain the Csibra (2001) null result with 5-month-olds, because the illusory figure in that experiment had a support ratio of .69, slightly greater than the ratio at which Otsuka et al. (2004) obtained a positive result with infants younger than 5 months. Our conclusion is thus that support ratio is not the only factor determining whether a positive or a null result has been obtained in moving object occlusion studies. We know that in the case of fully visible occluders, occluder width is a determinant of perception of trajectory continuity in 4-month-old infants (Johnson et al., 2003), and further work indicates that infants in this age group only perceive trajectory continuity when the object is out of sight either for a short time or across a short distance (Bremner et al., 2005). This suggests that this process carries a perceptual load that is easily exceeded. Thus, although support ratio is evidently an important factor in the present case, having to be above a certain threshold to support the perception of the illusion, null results in the Csibra study and possibly in the wide illusory contour condition of our Experiment 1 probably resulted from the joint perceptual load of perceiving the illusory figure and interpolating the occluded trajectory component.

We believe that these findings further extend the understanding of infants' emergent perception of occlusion events. Unlike the case for adults, deletion and accretion of a moving object at occluding edges appears to be insufficient to specify an occlusion event and hence the presence of an occluder. However, the additional presence of a visible occluding edge and background occlusion (Experiment 3) is sufficient to specify an occluding surface, either for the full extent of the surface or, as in the case of the Kanizsa figure, only locally at the inducing elements. Given the contrasting negative result in Experiment 2 in which these cues were presented singly, it appears that the combination of cues is particularly important. It seems likely that only this combination serves to specify a surface closer in depth than the background, a key property of an occluding surface and an aspect of the Kanizsa illusion reported by adults.

Additionally, the positive finding for the case of the Kanizsa figure contributes further to understanding the conditions under which young infants can use illusory or incomplete information to specify a surface. Previous work has tended to focus on infants' perception of moving illusory surfaces, it being demonstrated that 5-month-olds are capable of using the simple cue of accretion and deletion of texture to perceive the nearer of two surfaces (Granrud et al., 1984). Furthermore, Johnson and Aslin (1998) demonstrated that 4-month-old infants perceived object unity when the classic rod and box display (Kellman & Spelke, 1983) was specified by motion shear or accretion and deletion cues alone. In their study, both rod and box were presented in lateral motion relative to each other and background. Thus, it appears that illusory contours are more easily detected when they are in motion and, under these conditions, have been demonstrated in infants younger than the 4-month-olds we observed (Johnson & Mason, 2002; Valenza & Bulf, 2007).

In summary, our results suggest that when the occluding surface is stationary and the infant's perceptual task is to perceive continuity of an object's trajectory behind this occluder, quite rich information is needed to specify the occlusion event. This supplements evidence that infants in this age group perceive trajectory continuity only if the temporal or spatial gap in perception is short (Bremner et al., 2005). However, 2-month-olds appear unable to perceive trajectory continuity even under the most supportive conditions. Thus, what we have found in this series of experiments provides important additional information about the nature of the emergent ability at 4 months of age. We know, however, that perception of trajectory continuity becomes more robust in subsequent months, at least to the extent of tolerating longer gaps in perception (Johnson et al., 2003). Future work will determine how these starting conditions are modified as infants develop: specifically, whether there is a reduction in the strength and number of cues needed to specify an occlusion event as infants' information processing capacities increase.

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