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Perception of occlusion by young infants: Must the occlusion event be congruent with the occluder?

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ABSTRACT

Four-month-old infants perceive continuity of an object's trajectory through occlusion, even when the occluder is illusory, and several cues are apparently needed for young infants to perceive a veridical occlusion event. In this paper we investigated the effects of dislocating the spatial relation between the occlusion events and the visible edges of the occluder. In two experiments testing 60 participants, we demonstrated that 4-month-olds do not perceive continuity of an object's trajectory across an occlusion if the deletion and accretion events are spatially displaced relative to the occluder edges (Experiment 1) or if deletion and accretion occur along a linear boundary that is incorrectly oriented relative to the occluder's edges (Experiment 2). Thus congruence of these cues is apparently important for perception of veridical occlusion. These results are discussed in relation to an account of the development of perception of occlusion and object persistence.

The ability to detect the persistence of objects during temporary occlusion by a nearer object is crucial to perceiving an enduring world, and there is now evidence that this capacity emerges in at least rudimentary form in early infancy. Most of the evidence supporting this conclusion arises from work investigating infants' response to moving object occlusion events in which an object moves across a display, disappearing and reappearing at the boundaries of an occluding screen.

One approach involves measuring eye tracking while the object is out of sight, and there is now converging evidence from different laboratories indicating that the proportion of anticipatory eye tracks increases from 4 months through the first year (Gredebäck & von Hofsten, 2004; Johnson, Amso, & Slemmer, 2003; Rosander & von Hofsten, 2004).

Another approach is to harness the habituation-novelty method to investigate object trajectory perception (Fig. 1). Infants are habituated to a display in which an object moves back and forth across a display screen, disappearing behind a centrally placed occluder, and looking preference is assessed between two test trials in which the occluder is absent but the object either moves continuously or discontinuously. 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.

Application of this approach suggests that 4 months is a pivotal age 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, Bremner, Slater, Mason, Foster, & Cheshire, 2003).

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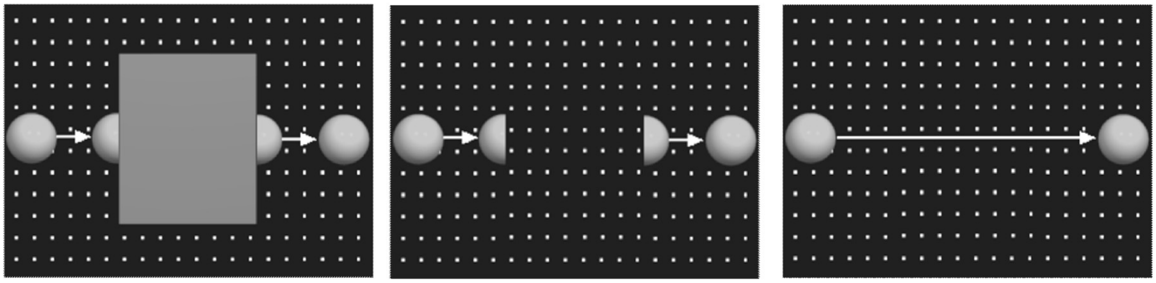

Fig. 1. Displays used by Johnson, Bremner et al. (2003) to investigate infants' perception of trajectory continuity, a) the habituation display, b) the discontinuous test display, and c) the continuous test display.

So far, 4 months is the earliest age at which infants have been shown to perceive trajectory continuity under these conditions, 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, Bremner et al., 2003). The evidence arising from the habituation-novelty method for emergence of this ability at 4 months and its increasing robustness across the following months is in keeping with the increase in predictive tracking emerging from eye-tracking research.

These data may be best explained in terms of a general perceptual processing account (Bremner, Slater, Johnson, 2014) in which infants attend selectively to different cues, singly and in combination, as indicators of both continuities and discontinuities in perceptual experience. For instance, 4-month-olds use changes in trajectory direction or height behind an occluder as a cue to discontinuity (Bremner et al., 2007), but do not use violation of smoothness of movement as a cue to discontinuity (Bremner et al., 2005). Also, 4-month-olds use the combination of color and shape change as information specifying a discontinuity in the moving object and hence perceive trajectory continuity, but do not do so when only shape or color is changed (Bremner, Slater, Johnson, Mason, & Spring, 2013). Likewise, information such as deletion and accretion of background, alignment of object parts (Johnson & Aslin, 1998), and figural goodness (Johnson, Bremner, Slater, & Mason, 2000) are cues that support perception of unity when an occluder hides part of an object.

This analysis leads to the question of minimum cues needed for young infants to perceive an occlusion event, and hence to perceive object continuity across occlusion. It is evident that deletion and accretion are sufficient to cue occlusion in adults, because they perceive object continuity even when there is no visible occluding surface (Kahneman, Triesman, & Gibbs, 1992; Kawachi & Gyoba, 2006; 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 (the tunnel effect, Burke 1952). Thus deletion and accretion appear to specify some sort of occluding surface. However, it appears that young infants are not subject to the tunnel effect cued by deletion and accretion information alone: 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 a continuous trajectory without an occluder. This preference presumably arises due to stimulus novelty (Bremner et al., 2005, 2007; Johnson, Bremner et al., 2003; see Fig. 1). If young infants perceive deletion and accretion alone as sufficient information for an occluding surface, one would predict either a null result or a preference for the continuous trajectory because it differs more from either of the two deletion and accretion events (the habituation event and the discontinuous test event). Nevertheless, it does appear that deletion and accretion are important cues to occlusion for young infants (Granrud et al., 1984), and Bertenthal, Longo, and Kenny (2007) demonstrated that, in comparison with deletion and accretion, instantaneous disappearance or implosion were not good cues to object persistence.

This raises a question regarding what information in addition to deletion and accretion is needed to support young infants' perception of object persistence through occlusion. The clearest information specifying an occlusion event is the presence of a luminance defined bounded surface whose edges coincide with deletion and accretion events, and work on trajectory perception demonstrates that provision of this information, along with deletion and accretion, is sufficient even in computer generated displays containing minimal explicit depth information (Bremner et al., 2005, 2007; Johnson, Bremner et al., 2003).

Additionally, Csibra (2001) demonstrated that 8-month-olds perceive the Kanizsa figure (Fig. 2; Kanizsa, 1979) as an occluding surface. More recently, Bremner, Slater, Johnson, Mason, and Spring (2012) demonstrated that presentation of a rectangular Kanizsa figure as an 'occluder' in a moving object occlusion event is sufficient to support perception of trajectory continuity by 4-month-olds. It is particularly striking that the Kanizsa figure is perceived as an occluding surface, because all the information leading to the illusory percept of a surface is situated at the *inducing elements* (the circles at the corners of the square); there is no such information in the direct path of the object. Thus it appears that at the age that marks the beginning of perception of trajectory continuity, the information necessary to specify an occluding surface is the combination of deletion and accretion, visible boundary, and background occlusion.

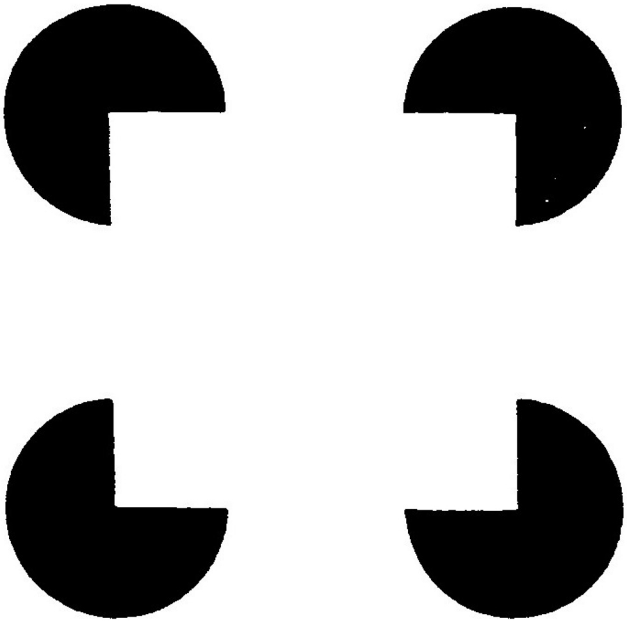

Fig. 2. The Kanizsa figure.

Given the conclusion that infants need a combination of cues to detect an occlusion event, the present work addresses the important question of how these cues must be combined to be effective. One possibility is that their effect is additive in a very simple way, such that their presence in sufficient number is sufficient to specify an occlusion event. Thus it is possible that occluding surface edges and the occlusion event need not be precisely spatially contiguous for the event to be interpreted as a normal occlusion. Some support for this possibility arise from the fact that the virtual edges of the Kanizsa figure are enough to specify an occlusion event; the real occluding edges in the inducing elements are distant from the accretion/deletion events but are still sufficient. Alternatively, it is possible that infants are sensitive to the congruence/contiguity of cues, in which case a particular combination of cues may only be affective if the spatial arrangement between them is appropriate.

To investigate these alternatives, we carried out two experiments with 4-month-olds in which the stimulus conditions previously used to investigate perception of trajectory continuity (Bremner et al., 2005, 2007; Johnson, Bremner et al., 2003) were modified so that there was displacement (Experiment 1) or misorientation (Experiment 2) between the deletion/accretion events and the edges of the occluder.

1. 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, Bremner et al., 2003) to manipulate the position of the deletion and accretion event in the object's path of movement so that these did not coincide with the position of the edges of the occluder. Thus in one condition the deletion event occurred earlier and the accretion event occurred later than they should given the width of the occluder (Fig. 3, upper images), and in the other condition the deletion event occurred later and the accretion event occurred earlier than they should given the width of the occluder (Fig. 3, lower images). These displays were designed so that the maximum occluder width and maximum separation between deletion and accretion boundaries maintained time and distance out of sight well within the range in which 4-month-olds perceive trajectory continuity when the occluder edges and occlusion events are co-located (Johnson, Bremner et al., 2003).

1.1. Method

1.1.1. Participants

Twenty-four 4-month-old infants (M = 123.2 days; range 112–141 days; 14 girls and 10 boys) took part in the experiment. Two other infants did not complete testing, one due to fussiness and the other because of equipment failure. Twelve infants were assigned to each of the two 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, followed up by telephone contact near test age to those parents who volunteered to take part. Infants with reported health problems including visual

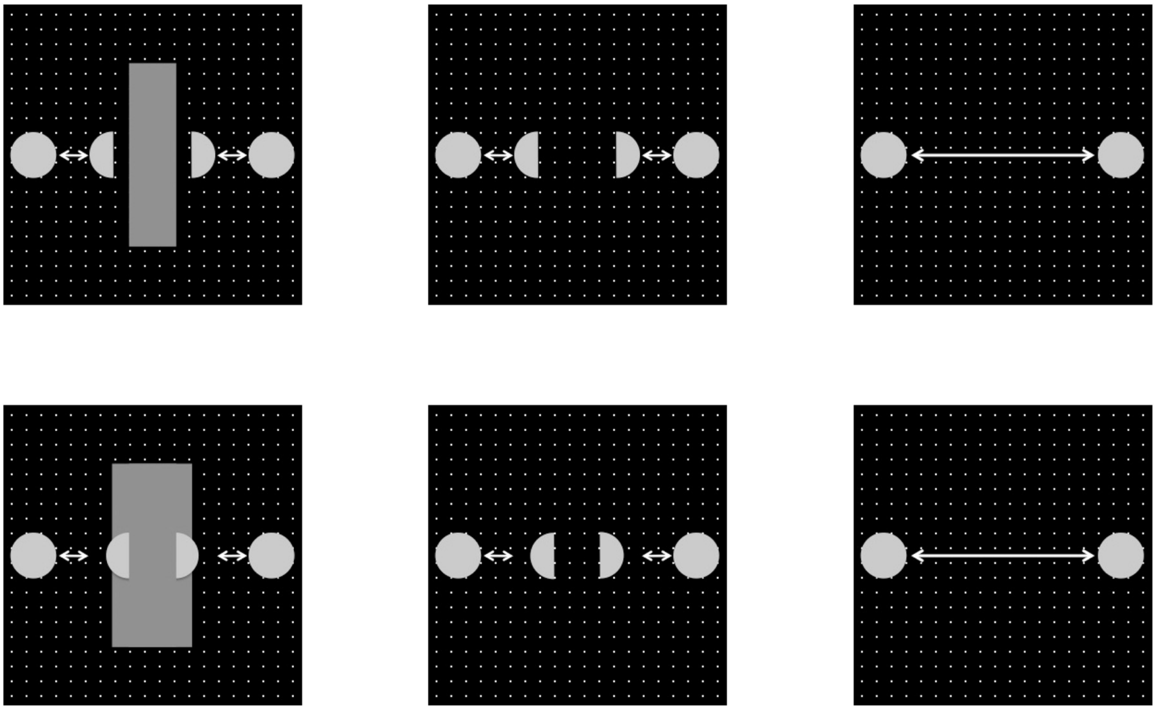

Fig. 3. From left to right, the habituation, discontinuous and continuous test displays used in the early deletion late accretion condition (top) and the late deletion early accretion condition (bottom) of Experiment 1:.

and hearing deficits and those born two weeks or more before due date were omitted from the sample. The majority of participants (over 95%) across both experiments were from Caucasian, middle class families.

1.1.2. 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 first observer's looking time judgments were input with a keypress on the computer keyboard.

Fig. 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° x 27°) serving as texture elements. A blue occluder with vertical extent 21.5 cm (12.3°) was placed centrally. 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). In the *early deletion late accretion display* the visible occluder was 7 cm wide, but the ball disappeared and reappeared at invisible contours separated by 12 cm. In the *late deletion early accretion display* the occluder was 12 cm wide, but the ball disappeared and reappeared at invisible contours separated by 7 cm. It took 2500 ms for the ball to traverse the width of the display. Time from complete visibility to invisibility or the reverse was 400 ms. Time totally out of sight was 366 ms. (early deletion late accretion display) or 67 ms (late deletion early accretion display). Time completely in sight to the left and right of the occluder was 1332 ms (early deletion late accretion display) or 1634 ms (late deletion early accretion display). 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 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.

1.1.3. Procedure

Each infant was seated 100 cm from the display and tested individually in a darkened room. The habituation display was presented until looking time declined across four consecutive trials, from the second trial on, adding up to less than half 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 when the infant looked away. A trial was terminated when the observer released the key for two seconds or 60 s had elapsed. Between trials, a beeping target was shown to attract attention back to the screen. Following habituation trials, infants were presented with the two test trials in alternation, three times each, for a total of six trials. On test trials, half the infants in each condition were presented with the

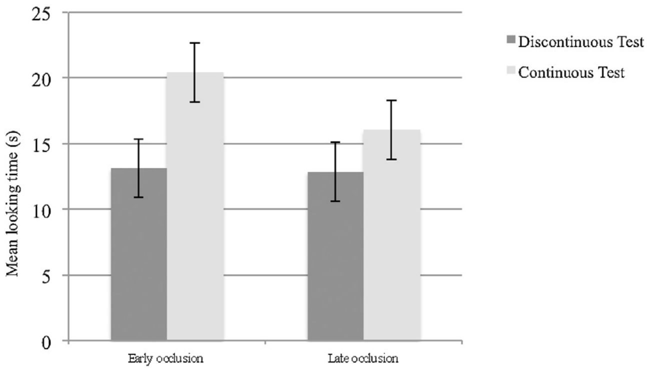

Fig. 4. Mean looking times to the two test displays for the two conditions in Experiment 1. Error bars in this and the subsequent data figure display standard errors.

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 two experiments in this report (*M* Pearson $r = 0.99$). In this experiment we did not run control conditions consisting of test trials alone to assess intrinsic preferences because we have obtained null preferences in control conditions with identical test trials in previous work (Bremner et al., 2005; Johnson, Bremner et al., 2003).

1.2. Results

Analysis of data from habituation trials indicated no difference between conditions in trials to habituation (early deletion late accretion condition, $M = 7.83$; $SD = 1.27$: late deletion early accretion condition, $M = 7.75$; $SD = 1.66$; $t(22) = 0.138$, $p = 0.89$) or in total habituation time (early deletion late accretion condition, $M = 201.2$ s; $SD = 90.86$; late deletion early accretion condition, $M = 217.1$ s; $SD = 77.52$; $t(22) = -0.46$, $p = 0.65$).

Fig. 4 shows looking times at the two test displays for each condition. Infants in both the early deletion late accretion and late deletion early accretion conditions looked longer at the continuous test trial, although this was more marked in the early deletion late accretion condition. 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. Firstly, infants were habituated to a standard criterion, circumstances under which familiarity preferences rarely occur (e.g., Fiser & Aslin, 2002; Johnson et al., 2009; Moore & Johnson, 2011). Secondly, several papers (Bremner et al., 2005, 2007; Johnson, Bremner et al., 2003) have reported systematic age related data that would be very hard to interpret on the basis of familiarity preference.

Because looking time data tend to be positively skewed, violating an assumption of ANOVA, data in this and the subsequent experiment were log transformed prior to analysis. A 2 (display: early vs. late occlusion) x 2 (test trial order) x 2 (test trial type: continuous vs. discontinuous) x 3 (test trial block) mixed ANOVA yielded a significant effect of test trial type, $F(1,20) = 8.05$, $p = 0.01$, $\eta_p{}^2 = 0.29$. The interaction between test trial type and display condition was not significant, $F(1,20) = 0.82$, $p = 0.37$, $\eta_p{}^2 = 0.04$, nor were any other main effects and interactions.

1.3. Discussion

The rationale for this habituation-test approach is that the direction of the novelty preference indicates how infants have processed the habituation stimulus. Thus infants' longer looking at the continuous test trial suggests that they processed the object's trajectory in the habituation display as discontinuous. This is the opposite result as is obtained for this age group with comparable times and distances out of sight when the occlusion event coincided with the visible occluding edges, and it certainly provides no evidence that infants perceived continuity in these habituation events. Thus we can conclude that the occlusion event must coincide spatially with the occluding edges for infants to perceive an occlusion event indicating continuity of the object.

2. Experiment 2

Experiment 1 makes it clear that when the occlusion events are separated by 2.5 cm from the edges of the occluder, infants do not perceive the event as a normal occlusion in which the object persists. Our second question was whether the same result would be obtained if the edges of the moving ball at the boundaries where deletion and accretion took place were oblique, but had contact with the visible occluder edges. In this case, the separation between occlusion event and occluder edges is reduced, but the occlusion event takes a different form, occurring as if at oblique edges. Intuitively, this disjunction in the orientation of occluding contours and occluder edges seems subtler than the complete separation of event and edge

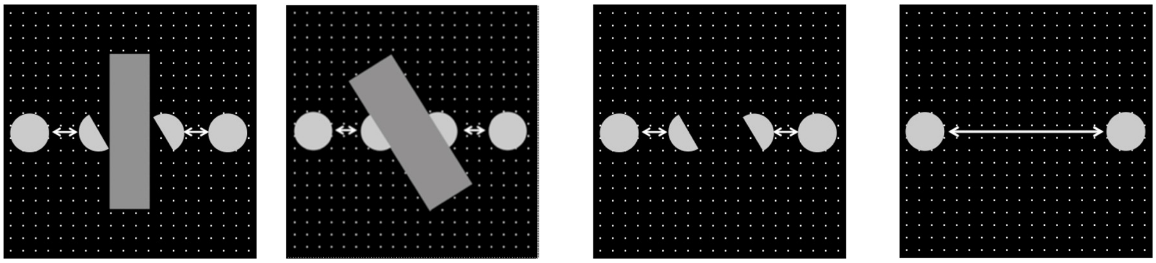

Fig. 5. From left to right, the experimental and baseline habituation displays, discontinuous and continuous test displays presented in Experiment 2.

in Experiment 1. However, it is possible that misorientation of occluding contour and occluder edge is as important as a simple displacement in the horizontal dimension.

Thus in Experiment 2 we exposed infants to a display in which the occluder had vertical edges but the occlusion event occurred at oblique contours. We know that 4-month-olds perceive trajectory continuity when a horizontally moving object passes behind an occluder with oblique edges (Bremner, Slater, Mason, Spring, & Johnson, 2016), so a negative result should not be due to occlusion at an oblique contour alone. However, because we had previously only tested infants' perception of occlusion across a very narrow oblique occluder, in this experiment we included a 'standard' baseline condition in which the occluder edges were oblique and the occlusion event was congruent with these edges, and also a control condition in which infants were only exposed to the test trials (to assess any intrinsic preference for either trial).

2.1. Method

2.1.1. Participants

Thirty-six 4-month-old infants ($M = 122.9$ days; range 109-138 days; 17 girls and 19 boys) took part in the experiment. Eight other infants did not complete testing due to fussiness. 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.

2.1.2. Apparatus and stimuli

The same apparatus as in Experiment 1 was used for stimulus presentation, video recording of the infant, and recording looking times. Fig. 5 indicates the displays used in this experiment. In the experimental condition, the habituation display was presented against a black background with a 20×20 grid of white dots measuring 48×48 cm (27° x 27°) serving as texture elements. An occluder with vertical and horizontal dimensions 21.5 cm (12.3°) and 7 cm (4°) was placed centrally. A 6.7 cm (3.8°) green ball moved back and forth from one side of the display to the other, undergoing progressive deletion and accretion at oblique linear contours at 55 $^\circ$ to the vertical, intersecting with the left and right edges of the occluder at the points where the bottom and top of the ball respectively contacted the occluder. In the baseline condition, the vertical occluder was replaced by an oblique occluder at 55 $^\circ$ to the vertical with length 21.5 cm and width 9.5 cm such that its occluding edges were congruent to the apparent edges at with deletion and accretion took place in the experimental condition. In both cases, time from complete visibility to invisibility or the reverse was 500 ms. Time totally out of sight was 233 ms and time completely in sight to left and right of the occluder was 1265 ms. 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. All other aspects of the form of the habituation and test trials were the same as in Experiment 1. We also included a control group who saw only the test trials.

2.1.3. Procedure

Infants were first habituated to the habituation display, and were then presented with the two test displays in alternation, three times each, for a total of six test trials. On test trials, half 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.

2.2. Results and discussion

Analysis of data from habituation trials indicated no difference between conditions in trials to habituation (experimental condition, $M = 7.5$, $SD = 2.28$; baseline condition, $M = 7.75$, $SD = 2.22$, $t\,(22) = -0.27$, $p = 0.79$) or in total time to habituation (experimental condition, $M = 151.2$, $SD = 45.81$; baseline condition, $M = 238.8$, $SD = 150.4$; $t\,(22) = -0.193$, $p = 0.076$).

As Fig. 6 indicates, infants in the experimental condition showed a consistent preference the continuous test display, whereas infants in the baseline condition showed a consistent preference for the discontinuous display, and infants in the control condition did not show a consistent preference for either test display. A 3 (condition: experimental vs. baseline vs. control) x 2 (test trial order) x 2 (test trial type: continuous vs. discontinuous) x 3 (test trial block) mixed ANOVA yielded

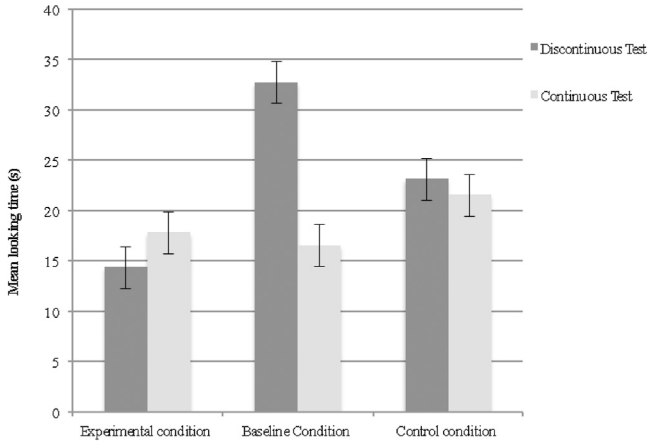

Fig. 6. Mean looking times to the two test displays for the experimental, baseline, and control conditions of Experiment 2.

a marginally significant effect of test trial type, $F\,(1{,}30) = 4.1$, $p = 0.051$, $\eta_p^2 = 0.12$, and a significant interaction between test trial type and condition, $F\,(2{,}30) = 14.74$, $p < 0.001$, $\eta_p^2 = 0.5$. To interpret this interaction, separate analyses were carried out for each condition. In the case of the experimental condition, there was a significant effect of test trial type, $F\,(1{,}10) = 5.49$, $p = 0.041$, $\eta_p^2 = 0.35$, with infants looking longer at the continuous test trial. There were no other significant main effects or interactions. In the case of the baseline condition, there was a significant effect of test trial type, F (1,10) = 20.51, $p = 0.001$, $\eta_p^2 = 0.67$, with infants looking longer at the discontinuous test trial, and a significant interaction between test trial type and test trial block, $F\,(2{,}9) = 4.42$, p = 0.046, $\eta_p^2 = 0.5$, due to an increase in the test trial type effect across trial blocks. In the case of the control condition, a 2 (test trial order) x 2 (test trial type: continuous vs. discontinuous) x 3 (test trial block) mixed ANOVA yielded only a significant effect of test trial block, $F\,(2{,}9) = 9.29$, $p = 0.006$, $\eta_p^2 = 0.67$. This is explained by longer looking on the first test trial block, and is a common effect in control conditions in which test trials are the only displays presented. The important finding is that there is no underlying preference for one test trial over the other.

In summary, infants in the experimental condition looked longer at the continuous test display, the opposite of the result shown by infants in the baseline condition. Apparently, unlike infants exposed to the baseline display, they perceived the habituation event as an object moving on a discontinuous trajectory. Thus it appears that an occlusion event that is wrongly oriented relative to the visible occluding edges does not provide information for object continuity.

General discussion

In both experiments, infants appeared to perceive the object's trajectory in the habituation display as discontinuous. This is despite the fact that in both experiments the display contained both visible occluding contours, and deletion and accretion events. These are circumstances under which infants would normally perceive trajectory continuity when occluding contours and deletion/accretion are congruent, providing the time and distance out of sight is sufficiently short, which they were in these experiments. Thus these studies contribute important additional information regarding young infants' perception of occlusion events, namely that the occlusion event must be spatiotemporally congruent relative to a visible occluder if it is to specify normal occlusion in which the occluded object persists. Although it is clear that multiple cues are needed to specify a normal occlusion event (Bremner et al., 2012), the effect of these cues is not simply additive; they must be spatially congruent to be effective.

We must acknowledge an alternative interpretation of the present results. Maybe the isolated deletion and accretion events are perceived as similar to the discontinuous test display, and so preference for the continuous display reflects a simple perceptual novelty preference. We believe that such an interpretation is unlikely, because infants showed a preference for the discontinuous test display in the case when the habituation display had a Kanizsa figure as a virtual occluder and thus contained particularly isolated deletion and accretion events. However, even if this is the appropriate interpretation of performance in the present experiments, our main conclusion remains unchanged, namely that deletion-accretion and occluder edges must be congruent if infants are to perceive an occlusion event in which the object persists while invisible.

In one sense, this conclusion should come as no surprise because to the adult eye these habituation displays do not look like cases of veridical occlusion. However, the results of this study attest to another respect in which young infants appear to perceive the world in adult-like ways. Specifically, there has to be precise spatial coordination between information for occlusion and information about the occluder. This is important in relation to the finding that young infants perceive the Kanizsa figure as an occluding surface. In this case, the explicit information specifying the occluding surface is distant from the occlusion event. Presumably the main point, however, is that although this information is distant it specifies a complete illusory surface that extends to and is congruent with the deletion and accretion events. What we cannot say is whether the degree of congruence required in the case of the Kanizsa figure would be the same as is required in the case of a visible occluder.

Our suspicion is that a high degree of spatial congruence would be required, whether or not the occluder is real or illusory. It seems likely that, even early in development, the visual system is tuned to detect veridical events, and spatial congruence of cues may be particularly important in this process. The fact that spatial alignment of inducing elements creates the illusion of a surface in the case of the Kanizsa figure probably points to the importance of alignment as a principle of perceptual organisation that exists early in development. If that conclusion is correct, then we can expect that spatial congruence of events is important for perception of veridical occlusion. By misaligning or misorienting the occlusion event relative to the occluder, our manipulations may thus have violated a key principle of perception of events in which one object passes behind another.

The aim of this work was to investigate the importance of cue congruence in 4-month-old infant's perception of occlusion events, with the focus on 4 months chosen because this appears to be a pivotal age in development of perception of object continuity across occlusion. However, it would be of interest to investigate older infants' perception of these displays. On the one hand, we might expect that older infant would not perceive trajectory continuity either, because these displays present non-veridical occlusion events and that we would expect a developmental progression towards detection of veridical events. On the other hand, we know that adults perceive an occlusion event on the basis of deletion and accretion alone (the tunnel effect), and at so some point in development in infancy or later we might expect participants to rely on this single cue alone. Thus far, it appears we have evidence that 6-month-olds do not use deletion-accretion alone to specify continuity (Johnson, Bremner et al., 2003), and future work will establish the age at which this emerges. It remains possible, however, that even in adults the presence of incongruent luminance defined occluding edges would disrupt perception of the tunnel effect.

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