Eye tracking provides no evidence that young infants understand path obstruction

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Highlights

- Eye tracking was used to test specific predictions relating to young infants' awareness of path obstruction.
- Our results provide no evidence that 4-month-olds are aware of path obstruction during occlusion.
- Four-month-olds are limited in their ability to represent the possible path of a moving object.

Abstract

In two experiments with 47 4-month-olds, we investigated attention to key aspects of events in which an object moved along a partly occluded path that contained an obstruction. Infants were familiarized with a ball rolling behind an occluder to be revealed resting on an end wall, and on test trials an obstruction wall was placed in the ball's path. In Experiment 1, we did not find longer looking when the object appeared in an impossible location beyond the obstruction, and infants did not selectively fixate the object in this location. In Experiment 2, after rolling one or two balls, we measured infants' fixations of a two-object outcome with one ball in a novel but *possible* resting position and the other in a familiar but *impossible* location beyond the obstruction. Infants looked longer at the ball in the possible but novel location, likely reflecting a looking preference for location novelty. Thus, we obtained no evidence that infants reasoned about obstruction and identified a violation on that basis.

Keywords: infant knowledge, path obstruction, eye-tracking, object solidity, object persistence, novelty preference

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1. Introduction

Many claims regarding infants' perceptual and cognitive abilities are largely based on fairly simple measures of looking duration at different visual displays. For example, the habituation-recovery technique and its variants have been widely used to provide evidence regarding perceptual discrimination in infancy (Bornstein, 1985; Spelke, 1985). The rationale in this case is that, following habituation to a criterion of looking reduction (usually 50% of initial looking averaged across three or four trials), recovery of looking will occur when a novel stimulus is presented that infants can discriminate from the original. Typically, test trials following habituation measure looking to the novel stimulus compared with looking time to the habituated stimulus, under conditions of simultaneous or sequential presentation. When infants are able to discriminate novel and habituated stimuli, following habituation they typically show a novelty preference reflected in longer looking at the novel stimulus. For instance, Baillargeon and DeVos (1991) reported that 4-month-old infants look longer at an event in which an object continued along a customary path despite another object blocking the path. Infants were habituated to an event in which an object moved behind an occluder and re-emerged; the occluder was then lifted and a second object was placed either on or behind the moving object's path. The occluder was then lowered to hide the second object, whereupon the moving object completed its customary movement, re-emerging from behind the occluder in both cases. Longer looking at the case in which the second object obstructed the path was taken as evidence for understanding of the conditions under which the second object presents an obstruction. That is, this result led to the claim that young infants understand the impenetrability of objects and hence the conditions under which one object blocks the path of another. A modification of the habituation method known as the Violation of Expectation (VoE) technique relies on the assumption that increased looking at an event reflects the infant's recognition that the event violates some aspect of physical reality; studies using VoE have reported that young infants seem to respond to impossible object events with brief prior exposure to familiarization events (Luo & Baillargeon, 2005) and even in the absence of familiarization trials (Wang, Baillargeon, & Brueckner, 2004).

In a variation of this approach, Spelke, Breinlinger, Macomber, and Jacobson (1992) first habituated infants to an event in which an object went behind an occluder to be revealed resting against an end wall when the occluder was subsequently lifted. On test trials an obstruction wall was placed in the path of the object, following which the object went behind the occluder, and was subsequently revealed either resting against the end wall (impossible but the perceptually familiar position) or resting against the obstruction wall (possible but a perceptually novel position). Infants of 2.5 months looked longer at the first outcome, and again this was interpreted as evidence that they understood that the moving object could not pass through the obstruction. Although several studies have reported the object impenetrability effect in young infants (e.g., Baillargeon, 1986; Baillargeon, 1987; Baillargeon, Spelke, & Wasserman, 1985), there have also been failures to replicate (Cohen, 1995; Cohen, Gilbert, & Brown, 1996).

For studies of infants' knowledge of path obstruction, a more specific prediction can be made than a simple looking time preference for the impossible event: If infants understand the impossibility of the event in which the object is revealed as having passed through the obstruction, longer looking should be directed *specifically at the object* in its impossible resting position. Thus, we can predict that infants will look longer at the object when it is revealed in an impossible position than when it is revealed in a possible but perceptually novel position. The goal of the present study was to evaluate this possibility by recording infants' eye movements with an eye tracker as they viewed object arrangements that would be considered possible or impossible on the basis of object impenetrability and path obstruction. Although eye tracking has been employed to investigate young children's understanding of path obstruction (for instance, Haddad, Kloos, &

Keen, 2008), to our knowledge this technique has not been used for this purpose with young infants.

Harnessing the more precise data that eye tracking yields may provide the potential to contribute more specific evidence relative to past studies regarding infants' knowledge, and perhaps to distinguish different levels of awareness. Although VoE data have been used to support the view that infants have quite precise knowledge of the world and the ability to reason on the basis of that knowledge, the same data could be explained by a much less specific level of awareness that something about an event is "not right" (Haith, 1998). At this level of knowing, infants might look longer at the event without pinpointing the specific aspect that makes it a violation, in this case the appearance of the object in an impossible position. Certainly, it appears that even two-year-olds do not use information about a barrier to guide search for an object that has rolled behind an occluder (Berthier, DeBlois, Poirier, Novak, & Clifton, 2000), and although three-year-olds use this information successfully (Berthier et al., 2000) they do not use this information consistently when it is put in conflict with other cues (Haddad et al., 2008). So even at two years, knowledge of barriers is not sufficiently well established to guide action, and at three years it is still somewhat fragile.

Given these considerations, our aim was to gather eye-tracking data to test a specific prediction that appears to arise from claims that young infants explicitly understand the physical principle of impenetrability. In two experiments, we investigated whether infants directed increased looking to an object when it was revealed in an impossible final location. We used both VoE and habituation methods (Experiments 1 and 2, respectively), and in both experiments we recorded overall looking (as judged by a trained observer) and infants' point of gaze (with an eye tracker) as they observed the events.

2. Experiment 1

In the first experiment, we performed conditions similar to those from Experiment 3 in Spelke et al. (1992). Specifically, we used an experimental condition in which infants were first familiarized with a sequence in which a ball was rolled from left to right. The ball disappeared behind an occluding screen that was then lowered to reveal the ball resting against an end wall (Figure 1a). Following these familiarization trials, infants saw test trials that began with an obstruction wall placed on the track by the experimenter before the screen was raised; when the screen was raised it hid all but the top of the obstruction wall. The ball then rolled down the track and behind the screen as during familiarization. There were two kinds of test trial. In the non-violation (possible) event, when the screen was lowered the ball was revealed resting against the obstruction wall (Figure 1b), whereas in the violation (impossible) event the ball was revealed resting against the end wall as before.

In addition to measuring looking times to the two test events in the conventional way (see below), we used an eye tracker to measure dwell times (accumulated gaze) in the region of the ball in its two locations (non-violation vs. violation). We predicted that infants would look longer overall at the violation test event, as measured by the experimenter's button press. This outcome would replicate the findings of Spelke et al. (1992) and confirm young infants' knowledge of impenetrability. Accordingly, we also predicted that infants would look longer at the ball when it was revealed in the impossible position against the end wall in the violation event vs. when it was revealed in the possible position against the obstructing wall in the non-violation event. We tested somewhat older infants than the 2- to 3-month-olds observed by Spelke et al. because eye tracking can be unreliable in infants of fewer than 4 months of age (Gredebäck, Johnson, & von Hofsten, 2010) and we reasoned that knowledge of impenetrability should be evident in 4-month-olds if it is available to 2- to 3-month-olds. We used six trials of familiarization rather than habituation because we reasoned we might obtain better-quality eye tracking data if infants were not bored prior to test, and we note prior successes in past studies using VoE to assess infants' object knowledge. Thus, the present study used eye tracking to investigate more precise predictions arising from a knowledge of impenetrability in young infants.

2.1. Method

2.1.1. Participants.

Nineteen 4-month-old infants (10 female) took part (M_{age} =127.1 days: range 118-147 days). This number is slightly greater than the 16 infants tested by Spelke et al. (1992) in their experimental condition. With an alpha level = .05 and power = .8, an N=16 was needed to detect a medium effect size. Nine additional infants were eliminated from the experiment because of: fussiness (n = 6) or poor eye tracking (n = 3). All participants were reimbursed with a gift (book) and £10 (travel expenses). In both 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 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 due date were omitted from the sample. The majority were from Caucasian, middle class families.

2.1.2 Materials.

Figure 1 illustrates the display, which consisted of a stage with an 82 (W) x 37 (H) x 24 (D) cm aperture with a curtain to the rear to allow the investigator access to the stage. A red 82 (W) x 2 (H) x 24 (D) cm track was placed on the stage to guide the ball. At the right-hand end of the track there was a bright blue 24 (W) x 17 (H) x 3 (D) cm end wall oriented so that its long dimension was at right angles to the path of the object. Another bright blue 24 (W) x 31(H) x 4 (W) cm obstructing wall, similarly oriented and placed 20 cm from the end wall, served as the obstacle in the test trials. A white 48 (W) x 19 (H) cm screen pivoting along its lower edge could be rotated so that it hid the end wall and all but 12 cm of the top of the obstruction wall. The ball used as the moving object was multicolored, had an animal paw pattern on one face, and had a diameter of 9.5 cm. A Tobii x60 eye tracker was positioned below the display and recorded infants' eye movements.

2.1.3. Procedure.

Infants viewed the display from a distance of 80 cm. Eye-tracker calibration was accomplished by a standard 5-point stimulus presentation on a 178-cm plasma monitor placed behind the stage. The Tobii eye tracker has a *M* spatial accuracy of about 1.2° visual angle (.9 cm at the infant's viewing distance; Morgante, Zolfaghari, & Johnson, 2012). The monitor was rotated out of the way once calibration was complete. Dwell times were measured relative to the image recorded by a scene camera placed behind and just above the infant's head. Following calibration and prior to commencing familiarization trials, an investigator appeared behind the display and greeted the baby, then ran her hand across the red track from left to right (infant's view), tapping the red track and end wall. This was repeated several times until infants had scanned the length of the stage. The investigator otherwise remained hidden behind the apparatus.

Each familiarization trial began with the screen being raised to conceal the right-hand stretch of track, followed by the investigator rolling the ball from left to right so that it travelled 28 cm at approximately 23 cm/sec before disappearing behind the screen. During these familiarization trials (and during test trials) the ball was oriented so that it rolled with the paw pattern in view, and the orientation of the paw in the ball resting position varied randomly across trials. Two seconds after the ball disappeared behind the screen, the screen was lowered to reveal the ball resting against the end wall. When the infant looked away for 2 seconds or more, the trial ended with the removal of the ball. This sequence was repeated for a maximum of 6 trials, followed by 6 test trials. Prior to the test trials the obstruction wall was placed in position directly in the infants' line of gaze and so that it obstructed the object's path behind the occluder (Figures 1b and 1c). The experimenter tapped the stage and the obstruction wall to ensure the infant had seen it. The screen was then rotated up to obscure all but the top 12 cm of the obstruction wall, whereupon the ball was rolled as in familiarization trials. Two seconds after the ball disappeared behind the screen, the screen was lowered to reveal the object resting either against the obstruction (possible, non-violation event but novel location, Figure 1b) to the left of the infant's midline, or against the end wall (impossible, violation event but familiar location, Figure 1c) to the right of the infant's midline. Violation and non-violation test trials alternated and their order was counterbalanced across participants.

2.2. Results

2.2.1. Looking time.

Figure 2 displays mean looking times to the violation and non-violation test trials, across trial blocks. Preliminary analysis revealed no main effect or interactions involving participant gender, so data were collapsed across this factor in the main analyses. A three-way mixed ANOVA with factors Test Trial (violation vs. non-violation), Test Trial Block (1 vs. 2 vs. 3), and Test Trial Order (violation event first vs. non-violation event first) yielded no significant main effects or interactions. Although infants on average looked longer at the violation events (M=6.95 s, SD=7.66) than non-violation events (M=5.48 s, SD=4.08), this difference was not significant, F (1,17) = 1.05, p = .32. Given that we did not get similar effects to those obtained by Spelke et al. (1992) with younger infants, and because their effect was largely limited to the first pair of test trials, we looked more closely at the pattern of results across pairs of test trials. Figure 2 indicates that the largest difference in looking between violation and non-violation trials occurred on the third test trial pair. However, this did not reach significance, t (18) = 1.27, p = .22.

2.2.2. Eye tracker dwell times.

We used the eye tracker to measure infants' gaze toward to the ball in the violation and non-violation test events by highlighting two circular areas of interest (AOIs) encompassing the ball in each image recorded by the scene camera. Dwell times to the ball in the non-violation and violation events consisted of accumulated gaze points in each of these two AOIs. The AOIs had the same diameter as the ball and corresponded to locations of the ball in the non-violation and violation displays (i.e., adjacent to the end wall and the obstructing wall, respectively). Gaze points were recorded at 60 Hz. One of the 19 infants we observed contributed no usable eye-tracker data and so was omitted from the analyses. Figure 3 displays mean dwell times to the violation and non-violation ball locations across trial blocks. A three-way mixed ANOVA with factors Test Trial (violation vs. non-violation), Test Trial Block (1 vs. 2 vs. 3), and Test Trial Order (violation first vs.

non-violation first) yielded no significant main effects or interactions. Although infants looked marginally longer at the ball in the violation location (*M*=3.35, *SD*=4.19) than the non-violation location (*M*=2.9, *SD*=3.13), this difference was not significant, F (1,16) = .47, p = .5.

2.3. Discussion

The difference in infants' looking at the violation than the non-violation outcome was not statistically significant, and eye tracking results indicated that infants did not look more at the ball when it rested at an impossible vs. a possible location. Thus, despite testing rather more infants than Spelke et al. (1992), and testing somewhat older infants, we obtained no evidence from either looking time or our dwell time measures to indicate that infants looked persistently at the ball when it was in a location that violated knowledge of object impenetrability. It seems unlikely that the age difference explains our failure to find similar effects to those of Spelke et al., because if anything our older infants should have shown a greater awareness of obstruction.

Possibly the discrepancy in results was due to a small number of familiarization trials in Experiment 1, which led to insufficient exposure to learn objects and their spatial positions. Although VoE effects have been reported to emerge on test trials even with no familiarization (Wang et al., 2004), it is nevertheless possible that there is a "hierarchy" of difficulty associated with the detection of different object principles, perhaps due to differences in processing load. Thus, whereas violation of some principles may be detected spontaneously, violation of other principles is only detected after infants have received substantial familiarization with the original event to "set" the typical event structure and allow for learning. According to one account (Thelen & Smith, 1994), for example, infants form a representation of the habituation event that includes likely future outcomes, and it is possible in Experiment 1 that an initial formation of a detailed representation of the objects and their spatial relations was not achieved. It is possible as well that the test events were insufficiently distinct in their depictions of violations of impenetrability. In Experiment 2, therefore, we repeated the methods of Experiment 1 with habituation rather than familiarization to the original event and with test trials designed to better highlight the impenetrability violation.

3. Experiment 2

In Experiment 1, looking time and eye-tracker data revealed a no evidence for looking more at the object in the impossible location. We reasoned that evidence for identification of the impossible event might emerge if infants were (a) first habituated to the rolling ball event depicted Figure 1a to ensure sufficient exposure and (b) presented at test with a direct comparison between objects in possible and impossible locations. Thus, in Experiment 2 we adapted the procedure used in Experiment 1 with two modifications. First, we included sufficient familiarization to ensure that habituation would take place by adopting a procedure incorporating strict habituation to criterion prior to test trials. Second, instead of presenting non-violation and violation outcomes across a sequence of trials, we presented outcomes in which two objects were present, one in a possible location adjacent to the obstructing wall, and the other in an impossible location adjacent to the end wall.

We tested outcomes of two conditions. In one condition, to allow comparability with Experiment 1, one ball was rolled on test trials as before, but when the screen was lowered, two were present in the possible and impossible positions respectively. However, we were mindful of the possibility that the presence of two balls would in itself appear impossible after only one was rolled. So, in a second condition, on test trials we rolled two balls in succession, whereupon in the test events two balls were revealed in possible and impossible locations. Because every test trial contained possible and impossible outcomes, overall looking time was not of interest and the focus was on whether infants looked longer at the ball in the impossible location than at the ball in the possible location. Analyses reported below, therefore, include only dwell time data.

3.1. Method

3.1.1. Participants.

Twenty-eight 4-month-old infants took part. There were 12 infants (8 male: M_{age} = 125.6 days: range 119-131 days) in Condition 1 and 16 infants (9 male: M_{age} = 121.6 days: range 100-136 days) in Condition 2. With an alpha level = .05 and power = .8, an N=14 per group was needed to detect a medium effect size. Twenty additional infants were eliminated from the experiment because of equipment failure during the testing session (n = 4), fussiness (n = 10), poor eye tracking (n = 5), and failure to habituate (1). All participants were reimbursed with a gift (book) and £10 (travel expenses).

3.1.2. Materials.

The materials used were the same as in Experiment 1 with the addition of a second identical 9.5 cm ball.

3.1.3. Procedure.

The habituation trials used the same events as described previously in Experiment 1 except that a strict habituation procedure was adopted. A trial was terminated when the infant looked away for more than 2 seconds or when 60 seconds had elapsed. During the habituation trials, the sequence was presented until looking time across four consecutive trials, from the second trial on, added up to less than half the total looking time during the first four trials. This sequence was continued for a maximum of 12 trials. All infants included in the analyses habituated according to these criteria. During the test trials that followed, twelve infants (condition 1) viewed one ball being rolled whereas sixteen infants (condition 2) viewed two balls being rolled, with a total of 6 test trials in both conditions. As in Experiment 1, the test trial began with a second wall placed in position directly in the infant's midline and so that it obstructed the object's path while behind the occluder. The experimenter then tapped the stage and the obstruction wall to ensure the infant had seen it. The screen was then rotated up to obscure all but the top 12 cm of the obstruction wall, whereupon either one ball (condition 1) or two balls (condition 2) were rolled from left to right. Two seconds after the ball disappeared behind the screen, the screen was lowered to reveal two balls, such that one was resting against the obstruction wall to the left of the infant's midline (the violation location) and another against the end wall to the right of the infant's midline (the non-violation condition).

3.2. Results

Preliminary analyses revealed no main effect or interactions involving gender that bore on the questions under investigation, so data were collapsed across this factor. Figure 4 displays the mean dwell times to the balls in the violation and non-violation locations, across the six test trials. A three-way mixed ANOVA with factors Location (violation vs. non-violation), Test Trial (1 to 6), and Condition (one ball rolled vs. two balls rolled), revealed a significant main effect of Location, F (1, 26) =20.48, p < .001, η_p^2 = .44, with infants looking significantly longer at the ball in the non-violation location (i.e., the new, possible location). There were no other significant main effects or interactions. Although the interaction between Condition and Ball was not significant, F (1, 26) = .83, p = .37, we carried out separate analyses to confirm that the effect was present in both conditions. Infants looked significantly longer at the ball in the non-violation location both in Condition 1 (one ball rolled), F (1, 12) = 5.07, p = .046, η_p^2 = .31, and in Condition 2 (two balls rolled), F (1, 15) = 19.02, p = .001, η_p^2 = .56.

3.3. Discussion

In this experiment the test trial outcome consisted of two balls, one in the violation and one in the non-violation location, and we obtained a clear looking preference for the ball in the non-violation location, the opposite of the result predicted if infants were aware of the impossibility of the ball being revealed in its old location beyond the barrier. Our result is instead in keeping with a response to the novelty of the new, though possible, location. Thus, following habituation to a standard criterion (as in Spelke et al., 1992), we obtained no evidence from gaze patterns that infants were aware of the impenetrability of the barrier. Notably, we obtained the same result whether one or two balls were rolled. This is of interest because one might imagine that if infants were reasoning about events, they would find the two-ball outcome a general violation after only one ball was rolled. That is, noting the numerical incongruity might have led infants to attend equally to both balls, because both contribute to the incongruity. Yet no such effect was obtained, and our result appears to be due to a position novelty effect in both conditions.

Finally, we considered the possibility that infants' greater looking toward the ball in the possible location was an artifact of eye tracking inaccuracy (i.e., AOI measurement error), and includes looking at the obstruction wall. However, a "heat map" (Figure 5) depicting clustered points of gaze across the 6 test trials shows that infants' attention was almost exclusively centered on the ball in either the left or right location, not on the wall.

4. General Discussion

Neither of our experiments yielded results in keeping with those of Experiment 3 of Spelke et al. (1992) or that support their interpretation. The looking time result in Experiment 1 showed a nonsignificant difference in looking during test trials at possible and impossible outcomes, despite the fact that our sample was somewhat larger, and older, than in Spelke et al. (1992). We also obtained no evidence from our eye-tracker measure that infants directed attention particularly to the ball in the violation location. In Experiment 2, in which each test trial contained balls in both possible and impossible locations, we obtained a result much more in keeping with perceptual novelty than a violation of the expectation of impenetrability due to path obstruction. It seems likely that infants looked longer at the ball in the possible location because its location was novel. Thus, the only clear effect to emerge appears best interpreted as reflecting a perceptual novelty preference.

In one respect, our results are unexpected. The conclusion by Spelke et al. (1992) that 2.5-month-olds understand path obstruction follows similar conclusions by Baillargeon (1986) concerning 6- to 8-month-olds, and Baillargeon and DeVos (1991) concerning 4-month-olds, and these findings together would lead us to expect similar results and direct eye-tracker evidence that infants identify the specific object that occupies an impossible position. However, our failure to obtain similar findings to those of Spelke et al. is in keeping with other replication failures of infant cognition studies (Bogartz et al., 1997, 2000; Cohen, 1995; Cohen et al., 1996; Rivera, Wakeley, & Langer, 1999; Sirois & Jackson, 2012; Wakeley, Rivera, & Langer, 2000; cf. Charles & Rivera, 2009; Jackson & Sirois, 2009; Schilling, 2000).

In another respect, our results are not surprising. It seems reasonable to assume that understanding path obstruction and what makes for an impossible resting position for a moving object involves the ability to perceive object persistence across occlusion. But we know that 4-month-olds have limited ability to perceive the continuous trajectory of an object across occlusion (Bremner, Johnson, Slater, Mason, Foster, Cheshire, & Spring, 2005; Johnson, Bremner, Slater, Mason, Foster, & Cheshire, 2003). Specifically, the longest period of total occlusion that allowed detection of trajectory continuity was 400 msec (Johnson et al., 2003), much shorter than the 2 sec absence in Spelke et al. (1992) and in the present work. We could not expect 4-month-olds to represent the hidden trajectory in its entirety across such a delay, and even if the infants only have to represent the trajectory of the ball up to the point at which it would contact the barrier, this occurs about 800 msec following total occlusion of the ball. However, it might be argued that perception of the invisible segment of the ball's trajectory is not required to detect that its resting place beyond the barrier is impossible. All the infants may need to do is to note that a ball has been rolled and, once the screen is lowered, detect that it has ended in an impossible position. Nevertheless, detection of what is impossible would still appear to imply representation of the path of the object prior to its revelation.

A further possibility is that some VoE effects reflect a much more basic awareness that all is not as it should be, an unreasoned impression that something is wrong in the violation condition (cf. Haith, 1998). Such an impression might not pinpoint the key problem, namely that the object is in an impossible place. That could explain why we obtained no eye-tracker evidence that infants attended selectively to the ball in the impossible position. It could also explain why in Experiment 2 we obtained selective attention to the ball in the possible location. Any basic level VoE response does not direct looking to either ball, but it is entirely possible that, in parallel, on a perceptual level infants show a positional novelty preference, which does draw attention to one ball.

There are a number of possible limitations of our work. Firstly, it is possible that infants in the current study did not demonstrate knowledge of path obstruction due to choices of design. For example, in the current study the occluding screen was pivoted rather than moving up and down as in the Spelke et al. (1992) study. We are aware of no theory, however, that ties infants' knowledge of object impenetrability to such specific constraints. And we must keep in mind that in Experiment 1 we did not manage to find the looking preference for the impossible outcome that emerged in Spelke et al. We conclude that any knowledge of path obstruction is fragile even at 4 months. And in light of the lack of selective attention to the ball in the impossible location, such knowledge would not appear to be based on precise spatial reasoning.

Secondly, as with much of the research literature, it is conceivable to construct alternative interpretations of our finding of looking preference for the ball in the possible but novel location. For example, as suggested by a reviewer, might infants show this pattern because they do not understand why, if one object penetrated the barrier, the other did not? Such an interpretation appears to us to involve a high level of abstract reasoning, abstract because it does not square with the normal rules of reality by which it is the ball at the *other* side of the barrier that has done the unexpected. The only evidence of which we are aware that children acted on information that an object had passed through a barrier was later in development with three-year-olds searching on the basis of direct visual evidence of a ball rolling beyond a barrier (Haddad et al., 2008). Thus, such an interpretation of our infants' responses appears low in plausibility. However, if correct, it would suggest that infants have no strong perception that objects cannot move through barriers, and thus would support our conclusion that eye tracking provides no evidence that young infants understand path obstruction.

Alternatively, might infants be exhibiting a looking preference for the *expected* outcome? There are cases in which infants show a perceptual familiarity effect rather than the more usual perceptual novelty effect, in particular, those in which habituation is insufficient or the events are particularly complex (Hunter & Ames, 1988). Such reversals are well documented for the perceptual habituation method, but we know of no cases in the extended VoE literature in which such reverse effects have been obtained. Indeed, such a reversal would effectively undermine the VoE effect, which is defined as longer looking to the unexpected or surprising event. Note also that we obtained the same result in Experiment 2, whether one or two balls were rolled. If rolling two balls made our task more complex we would have expected to find our effect only in that condition.

Thus, on the basis of both plausibility and parsimony, we favour a perceptual interpretation of our results. But even if one of the alternative interpretations above were plausible, we would still come to the same conclusion, namely that eye tracking provided no direct evidence of infants' understanding of path obstruction. Our favored conclusion is that young infants are not consistently engaged in forming expectations about events but that they generally respond robustly on the basis of perceptual novelty. It has been demonstrated that social looking to parent or investigator provides a measure of VoE (Walden, Kim, McCoy, & Karrass, 2007), and that VoE can be dissociated from perceptual novelty preference (Dunn & Bremner, 2017). Specifically, Dunn and Bremner showed that social looks were elevated in response to a VoE event in which an object changed form while behind an occluder but were low when a novel object was occluded and revealed. It may be that this measure, alone or in conjunction with others, will be needed for further development of our understanding of infants' knowledge of the world.

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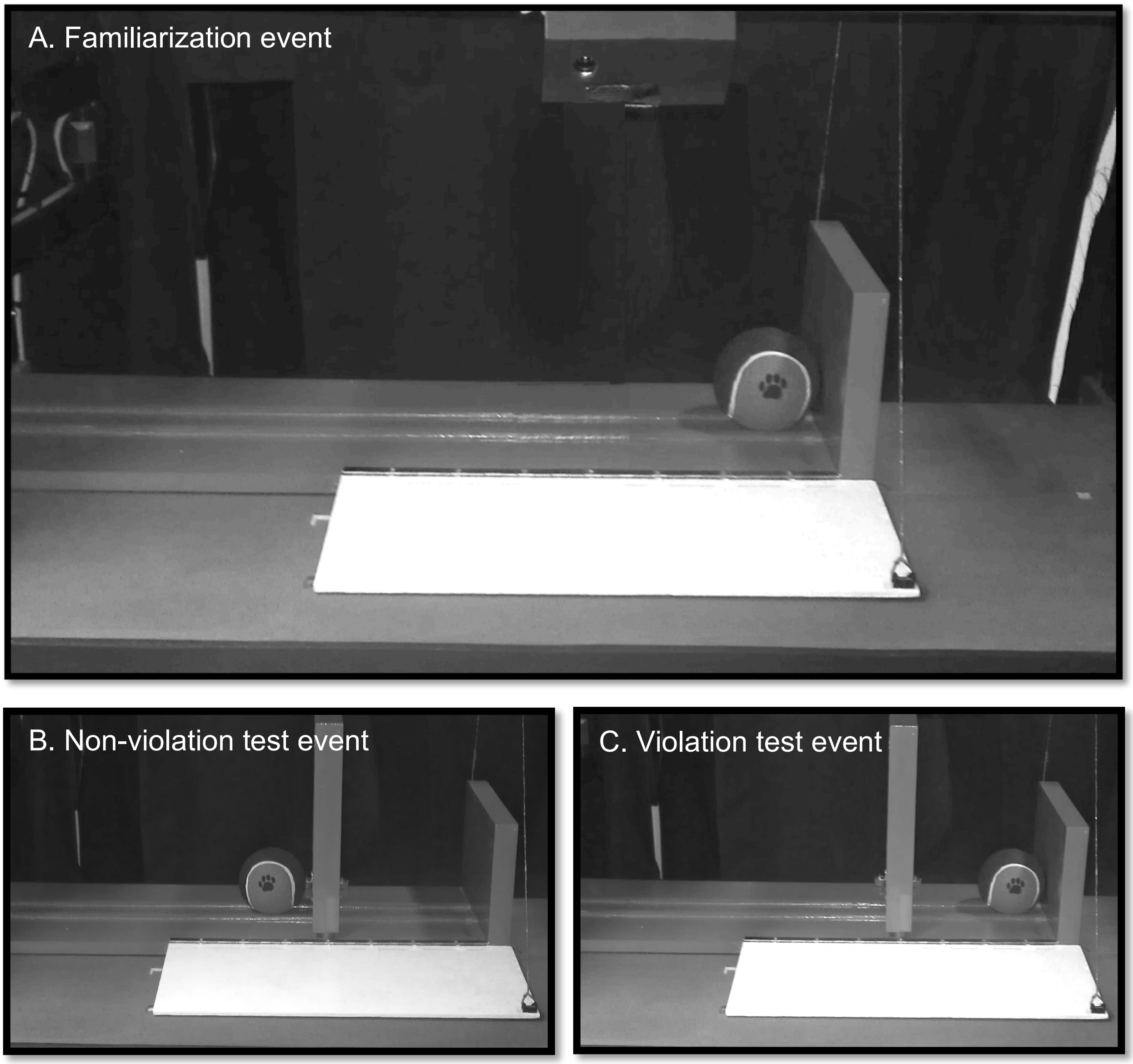

Figure 1. A. Familiarization event: the screen is rotated down to reveal the ball resting against the end wall at the right of the display. B. Non-violation test event: the screen is rotated down to reveal the ball against the central obstruction wall. C. Violation test event: the screen is rotated down to reveal the ball against the end wall.

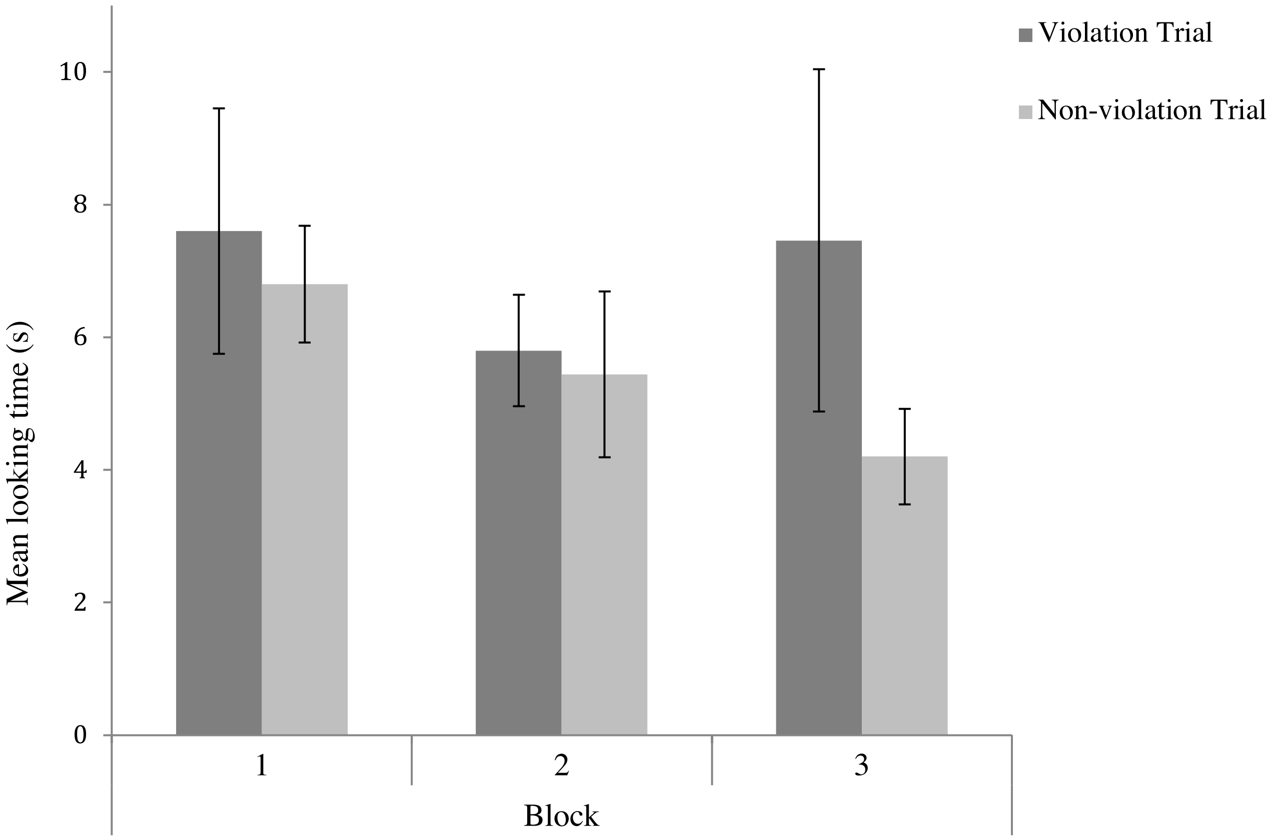

Figure 2. Mean looking times to violation and non-violation trials for each trial block in Experiment 1. Error bars in this and other plots are standard errors.

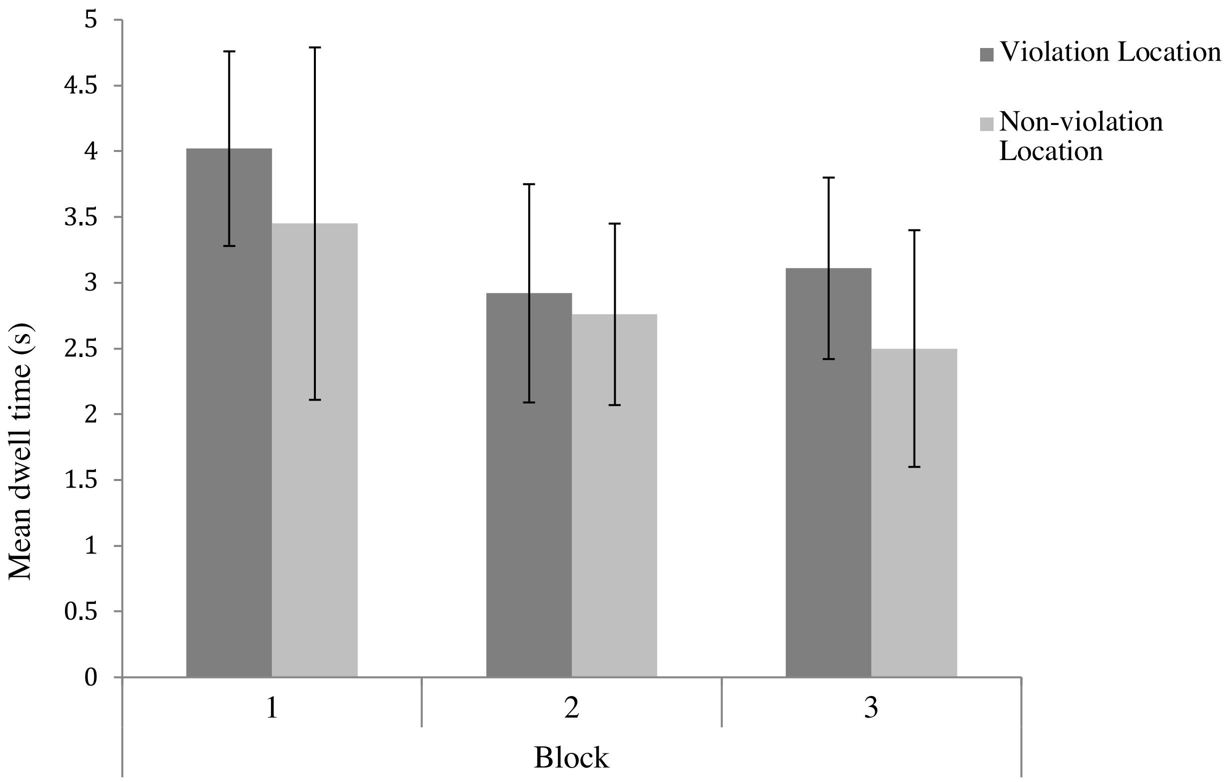

Figure 3. Mean dwell times to the ball in violation (right) and non-violation (left) locations in Experiment 1.

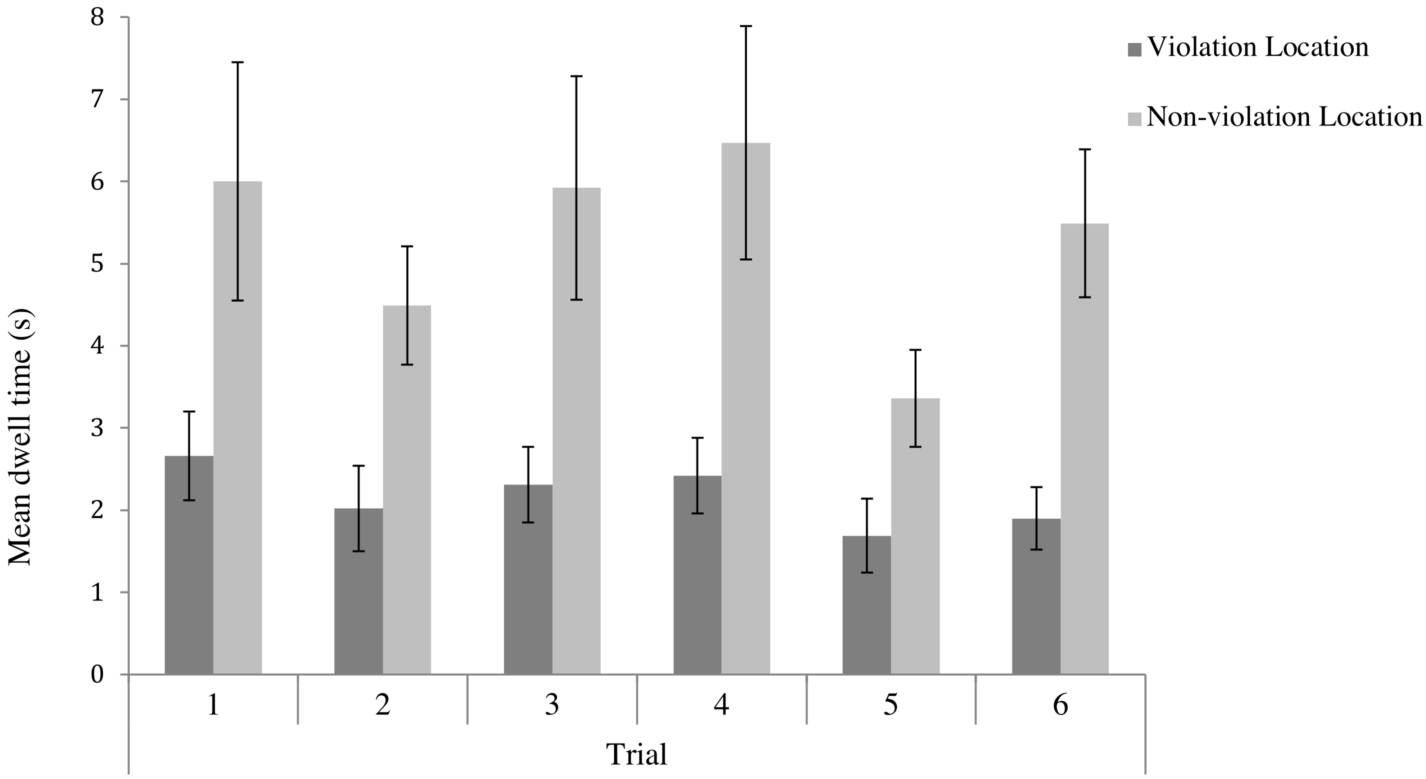

Figure 4: Mean dwell times to the ball in violation (right) and non-violation (left) location in Experiment 2.

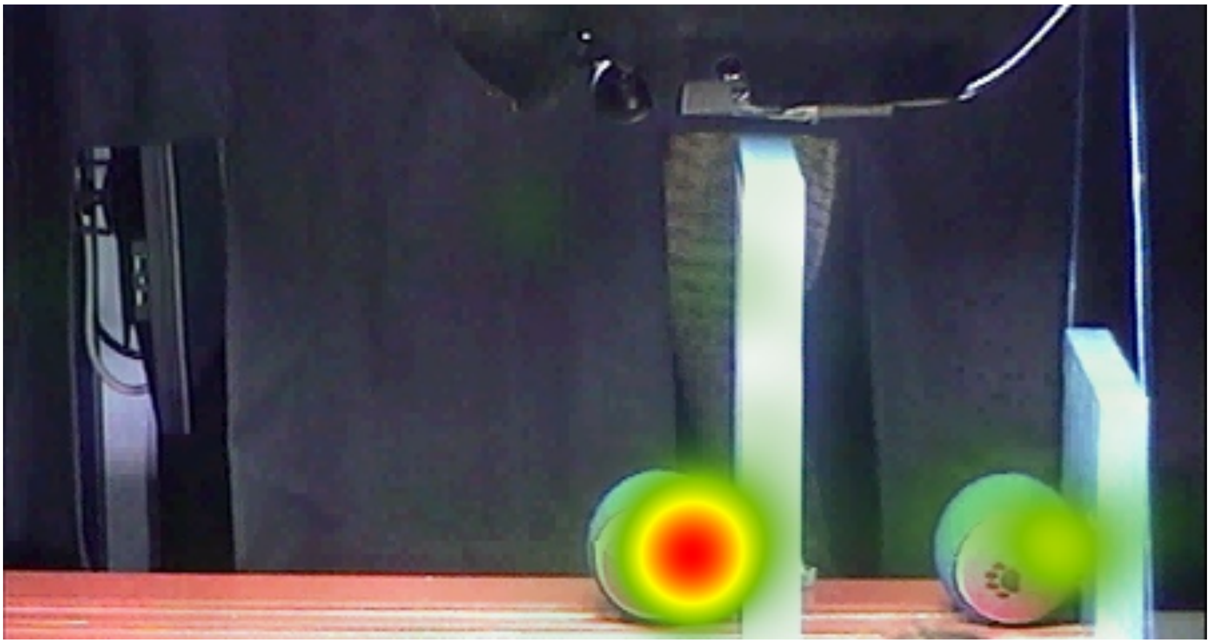

Figure 5. A “heat map” showing clustering of infants’ gaze in Experiment 2. The gradient from green, through yellow, to red indicates increasing concentration of gaze.