Developmental Psychology
1999, Vol. 35, No. 2, 427–435

0012-1649/99/$3.00

The Drawbridge Phenomenon: Representational Reasoning or Perceptual Preference?

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Two experiments investigated whether infants would look longer at a rotating "drawbridge" that appeared to violate physical laws because they knew that it was causally impossible, as claimed by R. Baillargeon, E. S. Spelke, and S. Wasserman (1985) and R. Baillargeon (1987a). Using a habituation paradigm, they reported that infants looked longer at a display that appeared impossible (rotated 180° while an obstructing box was behind it) than at one that appeared possible (rotated only 112°, appearing to stop at the box). Experiment 1 eliminated habituation to 180° screen rotations. Still, infants looked longer at the 180° impossible rotations. Critically, however, infants also looked longer at possible 180° rotations in Experiment 2, in which no obstruction was present. Moreover, no difference in effect size was found between the 2 experiments. These findings indicate that infants' longer looking at 180° rotations is due to simple perceptual preference for more motion. They question R. Baillargeon's (1987a) claim that it is due to infants' representational reasoning about physically impossible object permanence events.

Neonativist accounts of the origins of cognition claim that infants are innately endowed with representational knowledge about physical phenomena (e.g., Carey, 1985; Gelman, 1991; Keil, 1991; Leslie, 1995; Spelke, Breinlinger, Macomber, & Jacobson, 1992). Key to this claim is Baillargeon's (1987a; Baillargeon, Spelke, & Wasserman, 1985) research on infants' preferential looking at kinetic events involving occluded solid objects that appear to violate physical laws in the so-called drawbridge phenomenon. These findings have also been the basis for Baillargeon's (1987a, 1995; Baillargeon et al., 1985) claim that Piaget (1954) underestimated the extent of young infants' cognition of object permanence. Baillargeon (1995) maintains that violation-of-expectation experiments, including the drawbridge studies, have demonstrated that, contra Piaget (1954), "young infants, like adults, represent the existence and properties of hidden objects" (p. 367). According to Baillargeon (1987a), young infants' representational knowledge about object permanence reflects either innate representational reasoning (e.g., Spelke, 1985) or innate fast learning.

To create the drawbridge phenomenon, Baillargeon (1987a; Baillargeon et al., 1985) used a habituation paradigm. In both experimental and control conditions, infants were first habituated to a screen (the drawbridge) repeatedly rotating back and forth 180°. In the experimental condition, an obstructing box was introduced in the way of the rotating screen during the posthabituation test trials. This permitted presenting alternating possible and impossible variants of the habituation event during the posthabituation test trials. In the possible posthabituation variant, the screen repeatedly rotated back and forth only 112°, thus appearing to stop at the point of contact with the by now no longer visible obstructing box. In the impossible posthabituation variant, the screen repeatedly rotated back and forth 180°, thus appearing to pass through the by now no longer visible obstructing box. The control condition posthabituation test trials were identical except that no obstruction was introduced. In the posthabituation trials, infants were found to look longer at the 180° than at the 112° repeated back-and-forth screen rotations in the experimental condition but not in the control condition. On the basis of these findings, Baillargeon (1987a) concluded that young infants already know (a) that the occluded obstructing box continues to exist behind the screen and (b) that the screen cannot rotate through the solid box, such that (c) they are surprised and look longer when it appears to do so.

The present studies investigated whether infants' longer looking at the impossible 180° rotation condition of the drawbridge phenomenon is due to their representational reasoning about its apparent violation of physical laws or whether it is merely an experimental artifact that capitalizes on infants' perceptual preference for novelty, greater movement, or both. To make this determination, we followed the test procedures devised by Baillargeon (1987a), but we omitted prior habituation. The reasons for doing so were both theoretical and experimental.

The theoretical reason derives from Baillargeon's (e.g., 1987a) claim. It follows that if infants already possess the representational knowledge attributed to them by Baillargeon, then it should be unnecessary to habituate them to one type of repeated back-and-forth screen rotation (180°) for infants to look longer at impossible

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We extend special thanks to Matthew Schlesinger for his helpful insights in designing this project. We are especially grateful for the hard work and dedication of the research assistants: Azure Kacura, Sulki Kim, Nancy Lee, Kyra Lyons, Jaana Lehtinen, Shanti Prasad, and Lynna Tsou. We also gratefully acknowledge our computer programmer, Ephram Cohen, and the Institute of Human Development for supporting this research.

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(180°) than at possible (112°) rotations in the experimental condition. Indeed, Baillargeon (1987a) herself questioned whether such putatively representational and knowledgeable infants require prior habituation to repeated 180° back-and-forth screen rotations for them to show the effect (see also Baillargeon, Kotovsky, & Needham, 1995).

An experimental reason for omitting habituation was to eliminate the potential confound of novelty. In the experimental condition (Baillargeon, 1987a; Baillargeon et al., 1985), infants may pay greater attention to the posthabituation impossible event (180° rotation) merely because it is a novel variant of the habituation event (180° rotation) due to the introduction of the obstructing box, and not because it is an apparent violation of physical laws. (For detailed analyses of and findings on this and other potential confounds, see Bogartz & Shinsky, 1997; Bogartz, Shinsky, & Speaker, 1997; Fischer & Bidell, 1991; Haith, 1997; Lourenco & Machado, 1996; Montangero, 1991; Munakata, McClelland, Johnson, & Siegler, 1997; Schilling, 1997; Siegler, 1993; Thelen & Smith, 1994.)

Another potential confound in Baillargeon's (1987a; Baillargeon et al., 1985) procedure is the differential amount of movement displayed in the 112° and 180° rotations. In the test trials of Baillargeon's experimental condition, the 112° and 180° back-and-forth screen rotations differed not only in their apparent physical possibility and impossibility, but the 112° rotations also presented less action and movement to the infants than did the 180° rotations. Thus, infants may be looking longer at the 180° rotations because they prefer greater movement (e.g., Gibson, 1988; Kellman & Spelke, 1983; Piaget, 1952), not because the rotations are apparently impossible.

Baillargeon (1987a) discounted the significance of this disparity in amount of movement between the two displays because she found no looking-time differences in the control condition in which no obstructing box was present. Infants looked equally long at the posthabituation 112° and 180° rotations after having been habituated to 180°. However, if there was no difference in infants' intrinsic interest between the two rotations, posthabituation 112° rotations should have captured infants' attention more because they were novel whereas posthabituation 180° rotations were familiar. The fact that they looked equally long at both 112° (novel) and 180° (familiar) posthabituation rotations indicates that infants prefer 180° rotations that present more movement and that their perceptual preference for more motion is only partially suppressed by prior familiarization with repeated 180° rotations in the habituation phase.

To test this simpler alternative account of the drawbridge phenomenon (i.e., that infants look longer at the impossible 180° event because they prefer its greater movement), we conducted two experiments. The first experiment replicated Baillargeon's (1987a) experimental condition without prior habituation. The second experiment replicated Baillargeon's (1987a) control condition without prior habituation. We hypothesized that, without prior habituation, infants would look longer at the 180° than at the 112° back-and-forth screen rotations in Experiment 2 (in which both rotations were apparently possible) as well as in Experiment 1 (in which 180° rotations were apparently impossible and 112° rotations were apparently possible). Our expectation was that infants' longer looking time at the impossible 180° rotations is simply a function of their perceptual preference for greater action and movement and is not due to representational knowledge that this display violates what is physically possible.

This hypothesis led to the further prediction that the magnitude of looking longer at the 180° rotations should not be greater in Experiment 1 (in which they displayed apparent physical impossibility as well as more movement) than in Experiment 2 (in which they displayed only more movement). Our expectation was that the apparent impossibility of the 180° rotations in the experimental condition would not affect infants' visual attention. If both perceptual preference for more movement and representational conception of apparent impossibility are contributing factors, then the looking-time difference should be greater in Experiment 1 than in Experiment 2. If, however, only perceptual preference for more motion is a contributor, and representational reasoning about apparent impossibility is not, then the looking-time difference should be equivalent in both experiments.

Experiment 1: Impossible 180° Versus Possible 112° Rotations

Method

Participants. Participants were 24 full-term infants (12 male, 12 female) ranging in age from 5 months 2 days to 5 months 28 days (mean age = 5 months 16 days). Another 27 infants were excluded from the experiment, 26 because they failed to complete all four pairs of test trials due to fussiness[1] and 1 because of experimenter error. This exclusion criterion contrasts with Baillargeon (1987a), who included infants in the final analysis who did not complete all eight test trials. We did not include infants who did not complete all eight test trials so as to avoid having to analyze the data using a missing-data algorithm, and potentially inflating the degrees of freedom. All infants were from the greater San Francisco Bay Area. Parents were contacted first by letter and then by telephone; they were not compensated for their participation.

Apparatus. The apparatus was modeled after that used by Baillargeon (1987a). It consisted of a stagelike enclosure set into an opening in a room partition. The stage was 43 cm high, 88 cm wide, and 74 cm deep; the interior walls were decorated with pink and blue stripes; and the floor was painted blue. A mechanical, rotating gray cardboard screen (30 cm high by 28 cm wide) was mounted in the center of the stage, with the motor housed beneath the apparatus. A curtain mounted in front of the opening of the stage could be lowered after each trial by an experimenter who was completely hidden behind the apparatus. The testing room was dark except for a low illumination above the infant and a light mounted above and projecting down onto the stage.

As in Baillargeon's (1987a) study, a wooden box (25 cm high, 15 cm wide, and 5 cm thick) painted bright yellow and decorated with a two-dimensional clown face was used as the obstructing object in the test trials. During test trials, the box was placed on a platform situated behind the screen. The platform could be raised and lowered vertically, thus removing the box from the screen's path.

A video camera, mounted into the partition above the apparatus, was focused on the infant. This image was recorded onto videotape and was also projected on-line to monitors in two separate rooms in which observers recorded the infant's looking and state during the session.

[1] Of the 26 infants who were excluded because of fussiness, 6 were excluded during the familiarization trials. The remaining 20 infants completed the following numbers of test trials in a *good* state: 7 infants completed 1 test trial, 2 infants completed 2 test trials, 5 infants completed 3 test trials, 1 infant completed 4 test trials, 4 infants completed 5 test trials, and 1 infant completed 6 test trials.

Procedure. Before the experiment began, infants were allowed to play with the yellow clown-face box for a few moments to familiarize them with its properties. During the experiment, infants sat in a Sassy Seat attached to a low table situated in front of the stagelike enclosure. Infants sat approximately 100 cm from the center of the stage (and the point at which the screen rotated). Parents sat in a child-sized chair to the left and slightly behind their infants. The parents were instructed not to interact with their infants during the experiment.

Two experimenters worked behind the apparatus during the experiment. One experimenter raised and lowered the curtain at the start and end of the trials; the second experimenter raised and lowered the platform that held the box. These two experimenters could not see the infants, nor could the infants or parents see them. An observer in a separate room (the third experimenter), naive to the experimental condition and trials, watched the infants on a monitor and pushed a button when the infants looked at the display. A fourth experimenter, in yet another adjacent room, executed the computer program, recorded the session on videotape, and monitored the infants' state during the experiment.

A computer program sent a signal in the form of an LED light to the experimenters behind the apparatus, indicating the start of trials (and thus when to raise the curtain). The computer program also kept track of button presses from the on-line observer and sent signals either to the motor (to start or stop the movement of the screen) or to the LED light to signal the end of the trial (and thus when to lower the curtain). This procedure differed from that used in Baillargeon's (1987a) study, in which the rotation of the screen was done manually and two on-line observers viewed the infants through peepholes in the apparatus.

Rotation events. At the start of each screen rotation, the screen lay flat against the floor of the stage in the forward position with the clown-face box standing behind it on the platform. In the impossible event, the screen rotated 90° to an upright position and paused for 1 s. At that point, an experimenter lowered the platform supporting the box, removing it from the path of the screen. The screen then continued to rotate until it lay flat against the stage toward the back wall of the apparatus. It then immediately rotated back in the other direction, again stopping at 90° for 1 s (allowing time for the platform to be raised again), and then forward to its original position. This event was repeated continuously until the test trial was completed. In the possible event, the screen again rotated 90° to an upright position, paused for 1 s, and then continued to rotate until it completed a 112° arc (the place where the screen would have stopped had it contacted the box). It then paused for 2 s; rotated back in the other direction, again stopping at 90° for 1 s; and then rotated forward to its original position. In the possible event, as in the impossible event, the experimenter lowered and raised the platform during the pauses at 90°, keeping the slight sound cues consistent with the impossible event. This replicated Baillargeon's (1987a) procedure:

> The platform was moved in the same manner in all of the events to ensure that the sounds that accompanied the lowering and raising of the platform could not contribute to differences in the infants' looking times between and within conditions. (p. 658)

This possible 112° rotation event was repeated continuously until the test trial was completed. The screen rotated at a rate of 45° per second for each type of rotation. Each impossible event lasted 10 s; each possible event lasted 9 s.

Familiarization trials. Infants were presented with three familiarization trials. The interval between familiarization trials was 10 s. In the first trial, infants saw the yellow clown-face box on the stage, with the screen laying against the floor of the stage in the forward position. In the second and third familiarization trials, infants saw a single cycle of each type of screen rotation without the clown-face box being present. One half of the infants saw the 112° rotation on the second trial and the 180° rotation on the third trial, and the other half of the infants saw the reverse order. On the first familiarization trial, the trial ended (a) when the infants had looked away for 2 consecutive seconds after having looked for at least 10 cumulative seconds or (b) after the infants had looked at the display for 30 cumulative seconds. If the infants failed to look at the display for 10 cumulative seconds within 20 s, the trial ended. On the second and third familiarization trials, the single screen rotation began when the infants had looked at the apparatus for 2 cumulative seconds. The trial ended when the infants looked away from the display for at least 2 consecutive seconds or looked for 60 cumulative seconds or if they never looked in a period of 20 s.

Test trials. Infants were presented with 8 test trials, alternating between repeated possible and impossible events. The interval between test trials was 10 s. Trial order, impossible 180° or possible 112° event first, was counterbalanced across participants. The screen rotations began when the infants had looked at the apparatus for 2 cumulative seconds. The trials ended when the infants looked away from the display for at least 2 consecutive seconds or looked for 60 cumulative seconds. If the infants failed to look at the display for 2 cumulative seconds within 20 s, the trial ended. This actually occurred on a small number of trials, 8 of the total 192 included in the analysis.

Coding and reliability. Although we collected on-line looking-time data from the infants (particularly necessary because the length of trials was determined by infants' looks to the display), the looking-time data used in the analyses were not derived from these on-line observations but from subsequent coding of the video recordings of each experimental session. Because we used looking-time data based on video coding, the actual total looking time for a given trial could, in fact, be slightly longer than 60 s. This occurred when the live observer had recorded the baby looking away for a second or so but the video coding showed that the baby was actually looking during that time. The coding of video recordings was done using a JVC Professional Editing Recorder (Model BR8600U). This coding is unlike that used in Baillargeon's (1987a) study, in which the looking-time data analyzed came from the on-line observers. Reliability was assessed by comparing a second coder's results on 20% of the participants' sessions. Following Baillargeon's (1987a) procedure for calculating interobserver agreement, we calculated the number of seconds the coders agreed on where the infant was looking out of the total number of seconds the trial lasted and ignored disagreements of less than 0.1 s. Agreement between coders was 95%.

Results

Mean looking time to the first familiarization trial (the clown-face box) was 14.44 s. Looking time for the second and third familiarization trials was analyzed using a 2 × 2 mixed-model analysis of variance (ANOVA) with order (180° event first or 112° event first) as the between-subjects variable and event type (180° rotation vs. 112° rotation) as the within-subjects variable. The analysis revealed no significant differences in looking time to a single 180° rotation (M = 15.45 s, SD = 6.11 s) versus a single 112° rotation (M = 15.50 s, SD = 7.89 s) and no interaction between order and event type. This lack of difference in looking time to one type of screen rotation over the other is not surprising given that the familiarization trials consisted of only one 9- or 10-s screen rotation. Therefore, much of the 15 or so seconds of looking time in these trials was spent looking at the stage when the screen was lying flat.

Looking times for the test trials were analyzed using a 2 × 2 × 2 × 4 mixed-model ANOVA with order (impossible 180° event first or possible 112° event first) and gender as the between-subjects variables and event type (possible 112° vs. impossible 180°) and trial pair (first, second, third, or fourth pair of test trials) as the within-subjects variables. Two significant main effects emerged: event type, $F(1, 20) = 4.31, p < .05$, and trial pair, $F(3, 60) = 62.78, p < .001$. The main effect of event type indicates that, overall, infants looked longer at the impossible 180° test event (M = 27.42 s, SD = 10.19 s) than at the possible 112° test event (M = 24.66 s, SD = 13.26 s). The main effect of trial pair reveals that looking times decreased significantly across pairs (i.e., the infants appeared to habituate during the experiment).

A significant interaction between event order and event type also emerged, $F(1, 20) = 8.44, p < .01$. This two-way interaction reflected different looking patterns for the two orders. Post hoc comparisons revealed that when the infants saw the impossible event first, they looked significantly longer overall at the impossible event (M = 28.38 s, SD = 11.49 s) than at the possible event (M = 21.76 s, SD = 11.00 s), $F(1, 11) = 48.72, p < .0001$ (see Figure 1). However, when the infants saw the possible event first, they looked equally as long at the impossible event (M = 26.46 s, SD = 9.12 s) as at the possible event (M = 27.56 s, SD = 15.10 s), $F(1, 11) = 0.19, p > .05$ (see Figure 2).

In addition, the ANOVA revealed a significant interaction between order, event type, and trial pair, $F(3, 60) = 3.91, p < .05$. This three-way interaction was attributable to different patterns of looking across the trial pairs in the two conditions (see Figures 1 and 2). A simple, simple main effects analysis of this three-way interaction (Keppel, 1973) revealed two significant effects, both in the possible-first condition. Infants in this condition looked significantly longer at the impossible event on the first pair of trials, $F(1, 60) = 4.35, p < .05$, and actually manifested a significant preference for the possible event on the third pair of trials, $F(1, 60) = 9.90, p < .01$. The only significant effect involving gender in this analysis was a four-way interaction between order, gender, trial pair, and event type, $F(3, 60) = 3.01, p < .05$.

As we mentioned earlier, Baillargeon (1987a) included data from participants who did not complete all eight trials in her analyses. Therefore, determining whether the magnitude of the effect found in this experiment was comparable to that found in Baillargeon's experimental condition required the following calculation. Only the first two pairs of trials from Baillargeon's sample included complete data from all of the participants. Accordingly, we compared data from only our first two pairs of test

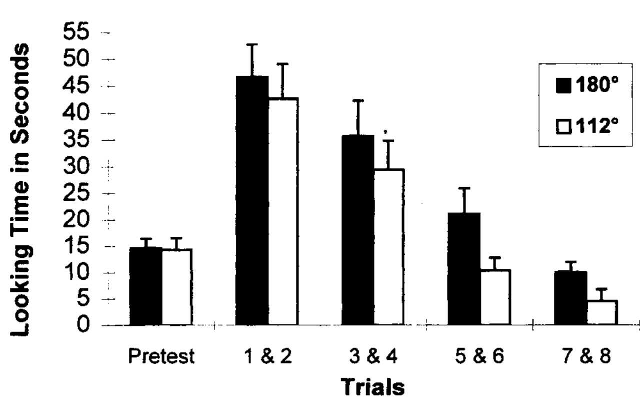

Figure 1. Experiment 1: Mean looking times and standard errors (represented by vertical lines) to impossible 180° versus possible 112° screen rotations across trial pairs for participants in the impossible 180°-rotation-first condition.

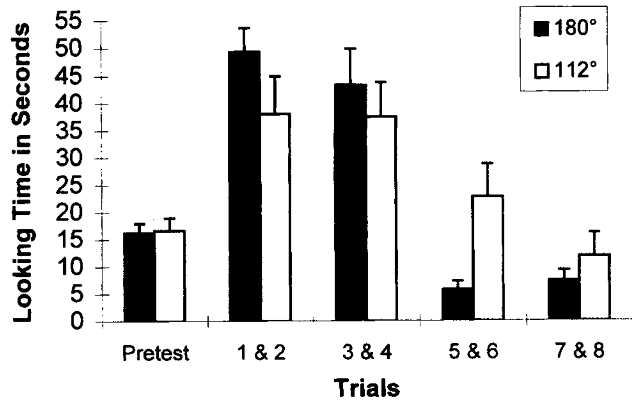

Figure 2. Experiment 1: Mean looking times and standard errors (represented by vertical lines) to impossible 180° versus possible 112° screen rotations across trial pairs for participants in the possible 112°-rotation-first condition.

trials with Baillargeon's data from the first two pairs of her experimental condition test trials (the only two pairs of trials from Baillargeon's sample that included data from all of the infants). To do this, we estimated the mean looking-time differences between 180° rotation trials and 112° rotation trials (posthabituation) on Pairs 1 and 2 from Baillargeon's (1987a) Figure 2 and compared them with our looking-time differences between 180° rotation trials and 112° rotation trials on Pairs 1 and 2. This revealed that the mean looking-time differences for our Experiment 1 (6.84 s) are comparable to Baillargeon's experimental condition looking-time differences (estimated as 7.16 s). The magnitude of the looking-time differences was less than 5%.

In addition to analyzing mean looking times, we also determined the number of infants who looked longer overall at the impossible 180° events (i.e., total looking time to the impossible trials was greater than that to the possible trials). A total of 17 infants looked longer at the impossible 180° events, whereas 7 looked longer at the possible 112° events. This difference was significant ($N = 24$, $x = 7, p < .05$, binomial test; Siegel, 1956). For the infants who saw the impossible 180° event first, all 12 looked longer overall at it. This difference was significant ($N = 12, x = 0, p < .001$, binomial test). In contrast, no significant difference emerged in the possible 112° event-first condition. Only 5 participants looked longer at the impossible 180° event, whereas 7 participants looked longer at the possible 112° event.

Discussion

Infants looked significantly longer at the impossible 180° event than at the possible 112° event. Thus, these infants showed the same preference for the impossible 180° event as that found by Baillargeon (1987a) and Baillargeon et al. (1985) even though these infants were not first habituated to repeated 180° back-and-forth rotations. Baillargeon (1987a) previously questioned the role of habituation:

> The main rationale for including these trials was to familiarize the infants with the (presumably unfamiliar) movement of the screen. However, it could be that such familiarization was not necessary and that the infants would have responded in the same way had they

> received no habituation trials. Another possibility is that the habituation trials served to acquaint the infants with the fact that the screen rotated freely through empty space but stopped rotating when it encountered a hard surface. (p. 658)

Our findings indicate that in fact this degree of familiarization (habituation) is not required for infants to look longer at the impossible 180° test event. If familiarization is in some way necessary, then the repeated presentation of these events in the course of the test trials is sufficient.

Indeed, there seems to be agreement that the longer looking at the impossible 180° rotations does not hinge on prior habituation. That is, the present findings are not unlike those Baillargeon et al. (1995) found when infants were not yet habituated. They reported that 6½-month-old infants who were given only one habituation trial showed a significant preference for the impossible 180° test events. However, Baillargeon et al. also reported that 6½-month-old infants did not show this preference when fully habituated. This finding is both surprising and contrary to their hypothesis that infants already possess representational knowledge about such physical phenomena.

Furthermore, Baillargeon's (1987a) speculative proposal that the necessary information in the habituation trials is that the screen "rotated freely through empty space" (p. 658) until it encountered a hard surface is insupportable. The reason is that the screen also always paused for 1 s when it had completed a 90° arc. Recall that in Baillargeon's experimental condition and in the present replication, the screen paused for 1 s after completing a 90° arc in both its backward and forward motion to allow the experimenter to lower and then raise the platform supporting the clown-face box. Thus, infants saw the screen stopping in midair when it did not encounter anything just as frequently as when it did.

We should also note that the order effect (i.e., infants looked longer overall at the impossible 180° event only when it was presented first) found, for example, by Baillargeon (1987a, 1987b) and Baillargeon et al. (1985) was robustly found in our data as well. Thus, the order effect was obtained whether infants were first habituated (as in Baillargeon's experiments) or not (as in the present experiment). It seems, then, that what is being found is not a general preference. It is particular to just one order, that is, a preference for 180° rotations when they come before 112° rotations. This calls into question even further the claim that the preference could index innate knowledge about the physical impossibility of the 180° test events (e.g., Spelke et al., 1992). It would, after all, require making the untenable claim that such an interaction effect is encoded in our genes.

Experiment 2: Possible 180° Versus Possible 112° Rotations

Having shown that the preference for the impossible 180° event is not dependent on prior habituation, we performed a second experiment to determine the basis for this preference. Baillargeon (1987a) speculated that infants' longer looking at the impossible 180° event than at the possible 112° event is based on their knowledge about possible versus impossible physical phenomena. A simpler alternative, which our second experiment was designed to test, is that infants' longer looking merely reflects their perceptual preference for 180° over 112° back-and-forth rotations because 180° events involve more action and movement than 112° events. Infants may look longer at the 180° rotation simply because they have a preference for its greater movement.

As we mentioned in the introduction, Baillargeon (1987a) rejected this alternative because she found no looking-time differences in her control condition in which infants saw alternating trials of 180° and 112° events without the obstructing box present. But, infants in her experiment were also first habituated to 180° rotations. If there were no difference in intrinsic perceptual interest between the two types of events, 112° rotations should have captured the infants' attention more because of their novelty relative to the habituation trials. The fact that they looked equally long to both suggests a preference for 180° rotations.

Accordingly, Experiment 2 tested the hypothesis that infants prefer to look at 180° over 112° back-and-forth rotations. This experiment is similar to Baillargeon's (1987a) control condition, except it does not first habituate the infants to the 180° screen rotation. This way neither 112° nor 180° rotations are more familiar or novel stimulus displays.

Method

Participants. Participants were a new sample of 24 full-term infants (12 male, 12 female) ranging in age from 5 months 2 days to 5 months 29 days (mean age = 5 months 20 days). Another 11 infants were excluded from the experiment, 6 because they failed to complete all four pairs of test trials due to fussiness,[2] 1 for failure to attend to the display, 3 because of equipment failure, and 1 because of procedural error by the mother. Participant recruitment was the same as in Experiment 1.

Apparatus. The apparatus was identical to that used in Experiment 1.

Procedure. The procedure was identical to that used in Experiment 1, except for the absence of the clown-face box. In addition, no familiarization trials were presented because no clown-face box was part of this experiment. Thus, the single rotation events presented in the familiarization trials of Experiment 1 would have been redundant with the test trials in this experiment.

Rotation events and trials. As in Experiment 1, the 8 test trials consisted of alternating repeated 180° and 112° back-and-forth screen rotations but without the box being present on the stage. Replicating Baillargeon's (1987a) control condition procedure, the experimenter continued to raise and lower the platform during the pauses at 90°, thereby keeping the slight sound cues consistent with those in Experiment 1. The screen rotations began when the infants had looked at the apparatus for 2 cumulative seconds and continued until the infants looked away from the display for at least 2 consecutive seconds after having looked for at least 5 cumulative seconds or looked at the display for 60 cumulative seconds. If the infants failed to look at the display for 2 cumulative seconds within 20 s, the trial ended. This occurred on only 4 of 192 trials included in the analysis.

Coding and reliability. Infants' looking time was coded from the video recordings of each experimental session using a JVC Professional Editing Recorder (Model BR8600U), as in Experiment 1. Reliability was assessed by comparing a second coder's results on 20% of the participants' sessions. The calculation procedure was the same as that used in Experiment 1. Agreement between coders was 97%.

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[2] Of the 6 infants who were excluded because of fussiness, 1 was excluded during the first trial. The remaining 5 infants completed the following number of trials in a *good* state: 1 infant completed 1 trial, 1 infant completed 3 trials, 1 infant completed 5 trials, and 2 infants completed 6 trials.

Results

Looking times were analyzed using a 2 × 2 × 2 × 4 mixed-model ANOVA with order (180° event-first or 112° event-first) and gender as the between-subjects variables and event type (180° vs. 112°) and trial pair (first, second, third, or fourth pair of test trials) as the within-subjects variables. Three significant main effects emerged: event type, $F(1, 20) = 6.43, p < .05$; trial pair, $F(3, 60) = 26.11, p < .001$; and gender, $F(1, 20) = 8.28, p < .01$. The main effect of event type indicates that, overall, infants looked longer at the 180° test event ($M = 28.52$ s, $SD = 12.39$ s) than at the 112° test event ($M = 24.36$ s, $SD = 11.22$ s). The main effect of trial pair reveals that looking times decreased significantly across pairs (i.e., the infants appeared to habituate during the experiment). The main effect of gender reveals that, overall, boys looked longer ($M = 31.46$ s, $SD = 10.24$ s) than girls ($M = 21.42$ s, $SD = 9.49$ s).

A significant interaction between event order and event type also emerged, $F(1, 20) = 6.01, p < .05$. This two-way interaction reflected different looking patterns for the two orders. Post hoc comparisons revealed that when the infants saw the 180° event first, they looked significantly longer overall at the 180° event ($M = 32.16$ s, $SD = 14.50$ s) than at the 112° event ($M = 23.98$ s, $SD = 12.96$ s), $F(1, 11) = 9.51, p < .01$ (see Figure 3). However, when the infants saw the 112° event first, they looked equally as long at the 180° event ($M = 24.88$ s, $SD = 9.04$ s) as at the 112° event ($M = 24.74$ s, $SD = 9.76$ s; see Figure 4). In addition, a significant two-way interaction between gender and condition emerged, $F(1, 20) = 8.44, p < .05$. Post hoc analysis revealed that this interaction was due to the fact that male infants looked longer overall ($M = 38.16$ s, $SD = 8.65$ s) than female infants ($M = 17.97$ s, $SD = 7.08$ s) when they were assigned to the 180°-first condition, $F(1, 10) = 19.56, p < .01$. In the 112°-first condition, the overall looking times of the male and female infants did not differ ($M = 24.76$ s, $SD = 6.92$ s vs. $M = 24.86$ s, $SD = 10.94$ s, respectively).

In addition to analyzing mean looking times, we also determined the number of infants who looked longer overall at the 180° rotations. A total of 16 infants looked longer at the 180° event, whereas 8 looked longer at the 112° event. This difference did not reach significance ($N = 24$, $x = 8$, $p = .07$, binomial test). However, for the infants who saw the 180° rotation event first, 10 looked longer overall at the 180° event, whereas 2 did not. This difference was significant ($N = 12$, $x = 2$, $p < .05$, binomial test). In contrast, no significant difference emerged in the 112°-first condition, because 6 participants looked longer at the 180° event and 6 participants looked longer at the 112° event.

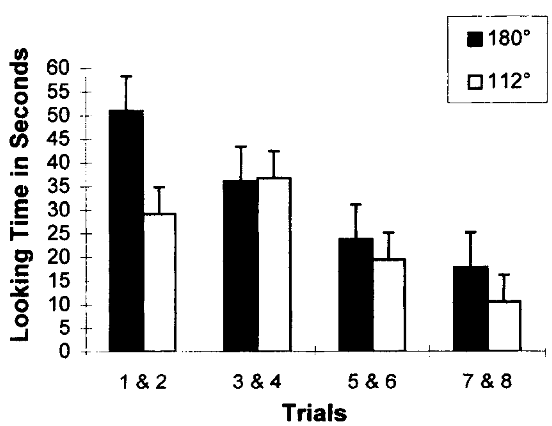

Figure 3. Experiment 2: Mean looking times and standard errors (represented by vertical lines) to 180° versus 112° screen rotations across trial pairs for participants in the 180°-rotation-first condition.

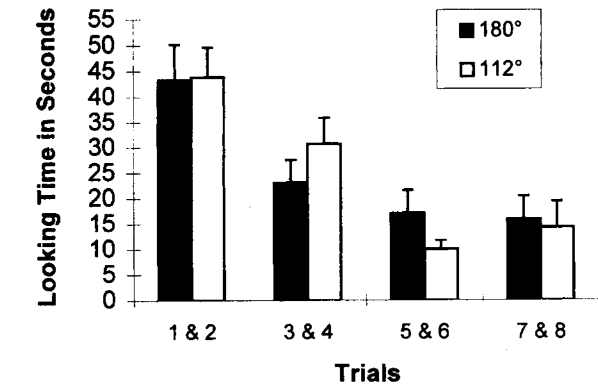

Figure 4. Experiment 2: Mean looking times and standard errors (represented by vertical lines) to 180° versus 112° screen rotations across trial pairs for participants in the 112°-rotation-first condition.

No difference emerged in the magnitude of longer looking at 180° than 112° rotations found in Experiment 1 and Experiment 2 (see Table 1). In Experiment 1, the mean preference for looking at the impossible 180° rotations over the possible 112° rotations was 2.76 s. In Experiment 2, the mean preference for looking at the possible 180° rotations over the possible 112° rotations was 4.16 s. The difference in mean preference for the 180° rotations between Experiments 1 and 2 was not significant (t test).

We performed a power analysis to determine what magnitude of difference in the mean looking-time preferences for 180° over 112° rotations between the two experiments could have been detected at a power of .8. This analysis revealed that given our sample sizes and variances, a difference of approximately 6.8 s was required to achieve statistical significance at $p < .05$. The actual difference between these mean preferences in the two experiments was only 1.40 s.

Moreover, the mean durations of looking at the 180° rotations that were apparently impossible when they were blocked by the box (in Experiment 1) and that were apparently possible when they were not blocked by the box (in Experiment 2) were practically identical (see Table 1). So too, the mean durations of looking at the 112° rotations that were apparently possible when they were blocked by the box (in Experiment 1) and when they were not blocked by the box (in Experiment 2) were practically identical (see Table 1).

Discussion

As we expected, infants had a significant perceptual preference for looking at the 180° screen rotations over the 112° screen rotations even when there was no obstructing box behind the screen during the 180° rotations. Infants' perceptual pref-

Table 1
Looking Time (LT) and Looking-Time Difference (LTD) in Experiments 1 and 2

	LT for 180° rotations		LT for 112° rotations		LTD for 180° − 112° rotations	
Experiment	*M*	*SD*	*M*	*SD*	*M*	*SD*
1	27.42	10.19	24.66	13.26	2.76	7.61
2	28.52	12.39	24.36	11.22	4.16	8.99
1 − 2 LTD	−1.10		0.30		−1.40	

erence for 180° rotations was revealed in this control experiment. Here, the test trials were not preceded by habituation to repeated 180° back-and-forth rotations as they were in Baillargeon's (1987a) control condition. In her control condition, the expectable, but not found, result should have been longer looking at the novel 112° than at the familiar 180° posthabituation test trials. Instead, equal looking time was found, a result that is also consistent with the hypothesis that infants prefer looking at 180° over 112° screen rotations. Taken together, then, all the findings support the hypothesis that it is the greater movement of the screen in the 180° event that is attracting infants' attention rather than the violation of an understood physical principle. Accounting for the findings does not require the rich interpretation that infants' behavior in this paradigm is based on representational reasoning about what is physically possible with solid objects.

As in Experiment 1, we found a significant order effect. Specifically, only infants who saw the 180° rotation first looked longer overall at the 180° rotations. Baillargeon et al. (1985) reported a similar finding in their control study in which 5-month-old infants were first habituated to the 180° event and then saw alternating posthabituation trials of the 180° and 120° events with the box sitting on the stage beside the screen. Infants who saw the 180° event first looked significantly longer overall at the 180° than at the 120° rotations.

The present additional finding of the same order effect adds yet another reason to investigate it further. Therefore, we cannot accept Baillargeon's (1987a) dismissal of the order effect as "theoretically uninteresting." Instead, it further questions the plausibility of those theoretical interpretations, not necessarily Baillargeon's, that longer looking at the impossible 180° rotations reflects innate representational knowledge in infants.

In addition, no difference was found in the magnitude of looking longer at the 180° rotations in Experiment 1 when an obstructing box made the rotations appear impossible versus in Experiment 2 when no obstructing box was present. Infants' preference for 180° rotations did not increase when this event was made to appear impossible by the presence of an obstructing box in Experiment 1. It confirmed our expectation that the apparent causal impossibility of the 180° rotations in Experiment 1 was not a contributing factor in determining infants' attention to the displays.

General Discussion

Three core related findings were made in these two experiments. Participants looked longer at the 180° than at the 112° repeated back-and-forth rotations when an obstructing box appeared to make the 180° rotations impossible, even without prior habituation to 180° rotations (Experiment 1). But, crucially, the same effect was found when no obstructing box was present to make the 180° rotations appear impossible (Experiment 2). Moreover, no difference was found in the magnitude of looking longer at 180° rotations when an obstructing box was present that made the rotations appear impossible (Experiment 1) versus when no obstructing box was present that made the rotations appear possible (Experiment 2).

These findings support the hypothesis that infants' longer looking at the apparently impossible 180° rotations is due only to simple perceptual preference for events that display more motion. The findings do not support Baillargeon's (1987a) rich interpretation that it requires representational knowledge about physically impossible "object permanence" events. Because apparent impossibility in the drawbridge experiments is confounded with greater movement of the screen, explanations based solely on infants' representational reasoning about the physical possibility of the events are insupportable.

The present findings remove key empirical support for neonativist claims (e.g., Spelke et al., 1992) that infants in this paradigm display adultlike reasoning about objects and causality. Indeed, even if one were to accept the interpretation that infants' longer looking at the 180° rotations is due to the presence of an obstructing object behind the screen, this would still not require more than an early form of object permanence cognition, specifically, an object-related expectancy. Piaget (1954) proposed that in infants' second object permanence stage, infants as young as 9 weeks old already expect a disappearing object to be where it vanished, and he presented longitudinal observations to support his proposal, of which the following is a sample from 2 participants younger than any of Baillargeon's (1987a) participants:

> Obs. [Observation] 2. In the realm of sight, Jacqueline, as early as 0;2 (27) follows her mother with her eyes, and when her mother leaves the visual field, continues to look in the same direction until the picture reappears. Same observation with Laurent at 0;2 (1). I look at him through the hood of his bassinet and from time to time I appear at a more or less constant point; Laurent then watches that point when I am out of his sight and obviously expects to see me reappear. Noteworthy too are visual explorations (O.I. [*The Origins of Intelligence in Children*], obs. 33), alternate glances (O.I., obs. 35) and reversed glances (*ibid.*, obs. 36) which attest to a sort of expectation of some familiar picture. (p. 9)

Critical in this regard is a major component feature of the drawbridge phenomenon: The obstructing box does not disappear permanently when it is occluded by the rotating screen. This is the case for both the test trials of Baillargeon's (1987a) experimental condition and of our replication in Experiment 1. Instead, after first appearing, the box disappears only momentarily (for between 6 and 7 s). Then it reappears (for between 3 and 4 s). Participants view this display of the box's "appearance, disappearance, and reappearance" repeatedly as the screen rotates back and forth. As a result, the display provides infants with multiple presentations of the box's continuing existence (i.e., that it is permanent).

In Piaget's (1952) theory, very young infants who are only at Stage 2 object permanence, and not 9-month-olds at Stage 4 as maintained by Baillargeon (1987a), should already expect the temporarily nonvisible box to continue appearing whenever the screen is not occluding it. During the 112° rotations, this simple expectation is not violated because there is always either a screen or a box in view. In contrast, at the end of each backward 180° rotation, this simple expectation is violated because there is a brief moment when infants do not see the box and the screen is lying flat toward the back wall of the stage. This account does not involve a notion of causal possibility or impossibility of the events. It requires only the simple expectation that the temporarily nonvisible box will continue to appear whenever the screen is not occluding it. Thus, longer looking at the 180° rotations could be attributable to an expectation that is based on a much earlier level of object permanence (i.e., Piaget's Stage 2) than that required according to Baillargeon (1987a).

An even simpler, albeit similar, potential explanation (still consistent with Piaget's [1952, 1954] theory) is that the infants merely held a very basic expectation that the box would reappear on each rotation. In the 180° rotations, the box was out of sight longer, and thus the infants may have searched longer than in the 112° rotations. Accordingly, then, the only time a violation of expectation would occur is if the box failed to reappear after the screen stopped at 90° in its forward movement on either type of rotation (which it never did).

The findings of Experiment 1 as well as those of Baillargeon (1987a) are consistent with the interpretation that infants look longer at the 180° rotations because they hold a simple expectation that the box will continue to reappear behind the screen. The findings are also consistent with the interpretation that infants look longer simply because they expect to see the box, and the box is out of their sight longer in the 180° rotations. However, longer looking due to such object-related expectancies cannot explain the findings of Experiment 2, in which no object was present and the infants still looked longer at 180° rotations. Moreover, if infants' longer looking at the 180° screen rotations in Baillargeon's experimental condition as well as in our Experiment 1 were due either to an object-related expectancy or (as Baillargeon has claimed) to infants' representational reasoning about the impossibility of the 180° event, then we would expect to find a greater difference in looking times between 180° and 112° rotations in Experiment 1 than in Experiment 2. In the 180° rotations in Experiment 1, there was a period of time when there was neither a screen nor a box visible and the screen appeared (to the adult observer) to rotate through the occluding box, whereas in the 180° rotations in Experiment 2, there was no box to create either an expectation for it to return or an illusion of causal impossibility. The finding of no difference between the two experiments in the magnitude of looking longer at the 180° rotations indicates that infants' greater attention to 180° rotations when the box was situated behind the screen is due neither to the absence of the object nor to the causal impossibility of the event.

The findings, then, are consistent with the interpretation that longer looking to 180° screen rotations, even when these events appear to violate physical laws, is simply due to infants' preference to look at events that display greater movement (e.g., Gibson, 1988; Kellman & Spelke, 1983; Piaget, 1952). The findings question Baillargeon's (1987a) proposition that representational reasoning by infants is necessary to account for this phenomenon.

References

Baillargeon, R. (1987a). Object permanence in 3½- and 4½-month-old infants. *Developmental Psychology, 23,* 655–664.

Baillargeon, R. (1987b). Young infants' reasoning about the physical and spatial properties of a hidden object. *Cognitive Development, 2,* 179–200.

Baillargeon, R. (1995). A model of physical reasoning in infancy. In C. Rovee-Collier & L. Lipsett (Eds.), *Advances in infancy research* (Vol. 9, pp. 305–371). Norwood, NJ: Ablex.

Baillargeon, R., Kotovsky, L., & Needham, A. (1995). The acquisition of physical knowledge in infancy. In D. Sperber, D. Premack, & J. Premack (Eds.), *Causal cognition: A multidisciplinary debate* (pp. 79–116). New York: Oxford University Press.

Baillargeon, R., Spelke, E. S., & Wasserman, S. (1985). Object permanence in 5-month-old infants. *Cognition, 20,* 191–208.

Bogartz, R. S., & Shinsky, J. L. (1997, April). *Object permanence in 5½-month-old infants?* Poster session presented at the biennial meeting of the Society for Research in Child Development, Washington, DC.

Bogartz, R. S., Shinsky, J. L., & Speaker, C. (1997). Interpreting infant looking: The Event Set × Event Set Design. *Developmental Psychology, 33,* 408–422.

Carey, S. (1985). *Conceptual change in childhood.* Cambridge, MA: MIT Press.

Fischer, K. W., & Bidell, T. (1991). Constraining nativist inferences about cognitive capacities. In S. Carey & R. Gelman (Eds.), *The epigenesis of mind* (pp. 199–235). Hillsdale, NJ: Erlbaum.

Gelman, R. (1991). Epigenetic foundations of knowledge structures: Initial and transcendent constructions. In S. Carey & R. Gelman (Eds.), *The epigenesis of mind* (pp. 293–322). Hillsdale, NJ: Erlbaum.

Gibson, E. J. (1988). Exploratory behavior in the development of perceiving, acting, and the acquiring of knowledge. *Annual Review of Psychology, 39,* 1–41.

Haith, M. M. (1997, April). *Who put the cog in infant cognition: Is rich interpretation too costly?* Invited debate on infant cognition presented at the biennial meeting of the Society for Research in Child Development, Washington, DC.

Keil, F. C. (1991). The emergence of theoretical beliefs as constraints on concepts. In S. Carey & R. Gelman (Eds.), *The epigenesis of mind* (pp. 237–256). Hillsdale, NJ: Erlbaum.

Kellman, P. J., & Spelke, E. S. (1983). Perception of partly occluded objects in infancy. *Cognitive Psychology, 15,* 483–524.

Keppel, G. (1973). *Design and analysis: A researcher's handbook.* Englewood Cliffs, NJ: Prentice Hall.

Leslie, A. M. (1995). A theory of agency. In D. Sperber, D. Premack, & J. Premack (Eds.), *Causal cognition: A multidisciplinary debate* (pp. 121–149). New York: Oxford University Press.

Lourenco, O., & Machado, A. (1996). In defense of Piaget's theory: A reply to 10 common criticisms. *Psychological Review, 103,* 143–164.

Montangero, J. (1991). A constructivist framework for understanding early and late-developing psychological competencies. In M. Chandler & M. Chapman (Eds.), *Criteria for competence: Controversies in conceptualization and assessment of children's abilities* (pp. 111–129). Hillsdale, NJ: Erlbaum.

Munakata, Y., McClelland, J. L., Johnson, M. H., & Siegler, R. S. (1997). Rethinking infant knowledge: Toward an adaptive process account of successes and failures on object permanence tasks. *Psychological Review, 104,* 686–713.

Piaget, J. (1952). *The origins of intelligence in children.* New York: International Universities Press.

Piaget, J. (1954). *The construction of reality in the child.* New York: Basic Books.

Schilling, T. H. (1997, April). *Four-month-old infants' "understanding" of possible and impossible events: A perceptual hypothesis.* Poster session presented at the biennial meeting of the Society for Research in Child Development, Washington, DC.

Siegel, S. (1956). *Nonparametric statistics for the behavioral sciences.* New York: McGraw-Hill.

Siegler, R. S. (1993). Commentary: Cheers and lamentations. In C. E. Granrud (Ed.), *Visual perception and cognition in infancy* (pp. 333–344). Hillsdale, NJ: Erlbaum.

Spelke, E. S. (1985). Perception of unity, persistence, and identity: Thoughts on infants' conceptions of objects. In J. Mehler & R. Fox (Eds.), *Neonate cognition: Beyond the blooming, buzzing confusion* (pp. 89–113). Hillsdale, NJ: Erlbaum.

Spelke, E. S., Breinlinger, K., Macomber, J., & Jacobson, K. (1992). Origins of knowledge. *Psychological Review, 99,* 605–632.

Thelen, E., & Smith, L. (1994). *A dynamic systems approach to the development of cognition and action.* Cambridge, MA: MIT Press.

Received August 13, 1997
Revision received May 26, 1998
Accepted June 1, 1998 ■