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Reasoning about the height and location of a hidden object in 4.5- and 6.5-month-old infants*

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Abstract

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The present experiments examined 6.5- and 4.5-month-old infants' ability to represent and to reason about the height and location of a hidden object. In Experiments 1 and 2, the infants were habituated to a screen that rotated back and forth through a 180°arc, in the manner of a drawbridge. Following habituation, a box was placed behind the screen, and the infants saw two test events. In one (possible event), the screen rotated until it reached the occluded box; in the other (impossible event), the screen rotated through either the top 80% or the top 50% of the space occupied by the box. The results indicated that (a) the 6.5-month-old infants were surprised when the screen rotated through the top 80%, but not the top 50%, of the box and (b) the 4.5-month-old infants failed to be surprised even when the screen rotated through the top 80% of the box (4.5-month-old infants do show surprise, however, when the screen rotates through the entire (100%) box (Baillargeon, 1987a)). Experiments 3 and 4 tested whether infants would be better at detecting that the screen rotated farther than it should if provided with a second, identical box to the side of the box behind the screen. This second box stood out of the screen's path and so remained visible throughout the test trials. The results indicated that with the second box present (a) the 6.5-month-old infants showed surprise when the screen rotated through the top 50% of the occluded box and (b) the 4.5-month-old infants were surprised when the screen rotated through either the top 80% or the top 50% of the box. The results of Experiment 5 revealed that the

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improvement in performance brought about by the second box disappeared when this box was no longer in the same fronto-parallel plane as the box behind the screen. Different models are considered to describe the impressive quantitative and qualitative physical reasoning abilities revealed by these findings.

1. Introduction

When adults see an object occlude another object, they typically assume that the occluded object (a) continues to exist; (b) retains its physical and spatial properties; and (c) remains subject to physical laws. Do infants make the same assumptions? In recent years, a number of researchers have addressed this question (e.g., Baillargeon, 1986, 1987a, 1987b, in press; Baillargeon & DeVos, 1990; Baillargeon, DeVos, & Graber, 1989; Baillargeon & Graber, 1987, 1988; Baillargeon, Graber, DeVos, & Black, 1990; Baillargeon, Spelke, & Wasserman, 1985; Hood & Willats, 1986; Rochat, Clifton, Litovsky, & Perris, 1989; Spelke, in press). The results of their experiments indicate that even young infants are able to represent and to reason about the existence and (at least some of) the properties of occluded objects.

One experiment, for example, examined 4.5-month-old infants' ability to represent and to reason about the *existence* of an occluded object (Baillargeon, 1987a). The infants were habituated to a screen that rotated back and forth through a 180° arc, in the manner of a drawbridge. Following habituation, a box was placed behind the screen, and the infants saw two test events. In one (possible event), the screen rotated until it reached the occluded box; in the other (impossible event), the screen rotated through a full 180° arc, as though the box were no longer behind it. The infants looked reliably longer at the impossible than at the possible event, suggesting that they (a) understood that the box continued to exist after it was occluded by the screen and (b) expected the screen to stop and were surprised that it did not.

Another experiment explored 7.5-month-old infants' ability to represent and to reason about the *height and location* of an occluded object (Baillargeon, 1987b). As in the previous experiment, the infants were habituated to a screen that rotated back and forth through a 180° arc. Following habituation, a tall, thin box was placed behind the screen, and the infants saw two test events. In both events, the screen rotated back and forth through a 165° arc. The only difference between the events was in the orientation of the box behind the screen. In one event (possible event), the box lay flat 10 cm behind the screen and was 4 cm tall; in the other event (impossible event), the box stood upright 25 cm behind the screen and was 20 cm tall. The 165°

screen rotation was consistent with the horizontal orientation of the box (the screen stopped rotating when it reached the box), but not with its vertical orientation (the screen rotated through the top 70% of the space occupied by the box). The infants looked reliably longer at the impossible than at the possible event, suggesting that they (a) represented the height and location of the box behind the screen; (b) used this information to estimate at what point the screen would contact the box; and (c) expected the screen to stop when it reached this point and were surprised that it did not.

The results of these and related experiments (e.g., Baillargeon, 1986, in press; Baillargeon & DeVos, 1990; Baillargeon & Graber, 1987, 1988; Baillargeon et al., 1985, 1989, 1990; Hood & Willats, 1986; Rochat et al., 1989; Spelke, in press) are important for several reasons. One is that they suggest that infant's conception of objects – as permanent entities that exist continuously in time and space – is similar to that of adults (e.g., Baillargeon, in press; Spelke, in press). Another is that they provide evidence that infants' ability to represent and to remember absent objects is far more sophisticated than has traditionally been assumed (e.g., Mandler, in press). Yet another is that they shed light on the nature and range of infants' physical reasoning abilities. This last issue is the main focus of the present paper.

2. The present research

Consider once again the two experiments described in the previous section. In the first (Baillargeon, 1987a), the infants were presented with a simple qualitative problem: should a rotating screen stop when an obstacle is placed in its path? In the second (Baillargeon, 1987b), the infants were presented with a more difficult, quantitative problem: at what point should a rotating screen stop when an obstacle of a given height is placed at a given location in its path? The second problem is referred to as quantitative (following the terminology used in computational models of common-sense physical reasoning; see Forbus, 1984) because it requires representing and reasoning about specific quantities, namely, the height and location of the obstacle. In the first, qualitative problem, there is no need to represent particular quantities. All that is necessary is to note the presence of the obstacle in the path of the screen; the specific height and location of the obstacle are irrelevant.

Baillargeon's (1987b) results indicate that 7.5-month-old infants are able to represent and to reason quantitatively about the height and location of an occluded object. The infants in the experiment not only understood that the screen should stop (qualitative prediction), but they also had expectations as to *where* the screen should stop (quantitative prediction). They were surprised when the screen rotated through the top portion of the space occupied by the box, suggesting that they realized that the screen rotated farther than it should.

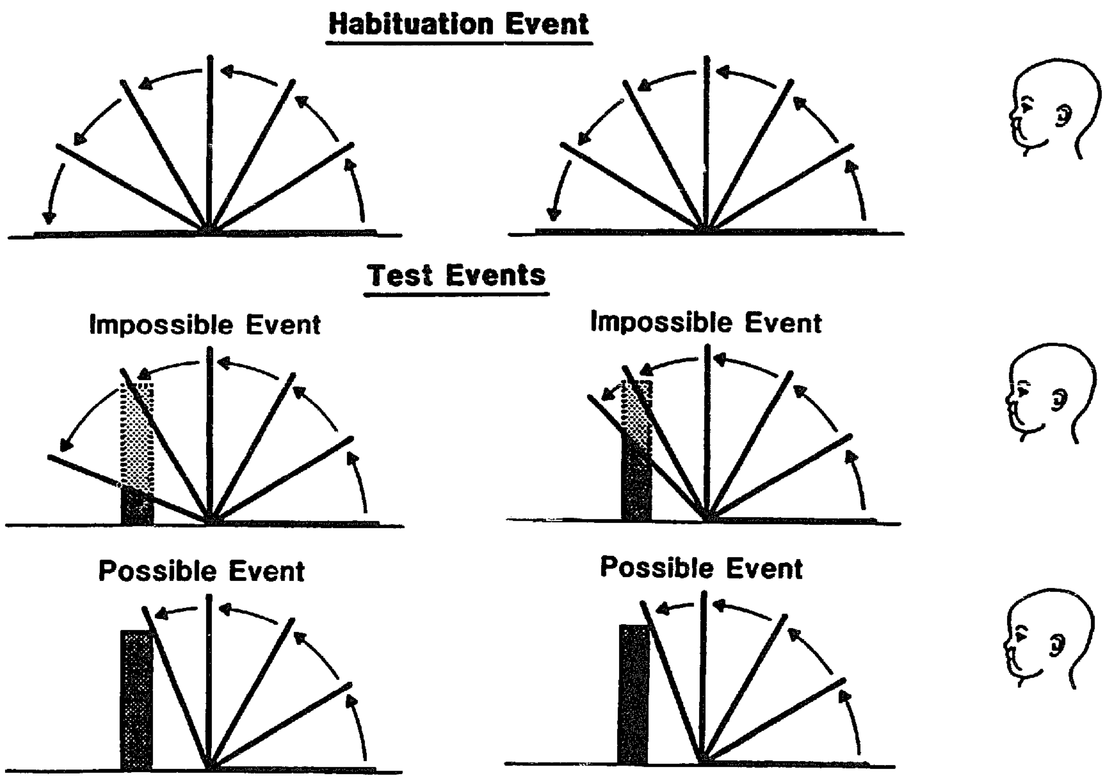
The present research addressed two questions raised by Baillargeon's (1987b) findings. First, would infants less than 7.5 months of age also be able to represent and to reason quantitatively about the height and location of an occluded object? Experiment 1 tested 6.5-month-old infants, and Experiment 2, 4.5-month-old infants. Second, how precise was infants' quantitative reasoning? In the impossible event Baillargeon (1987b) showed her subjects, the screen rotated through the top 70% of the occluded box – to adults, an obvious violation. Would infants still detect that the screen rotated farther than it should if it rotated through a smaller portion of the occluded box? The present experiments compared infants' performances with 80% and 50% violations.

3. Experiment 1

Experiment 1 examined the limits of 6.5-month-old infants' ability to represent and to reason quantitatively about the height and location of an occluded object. The method of Experiment 1 was simpler than that of Baillargeon (1987b) and was in fact similar to that used by Baillargeon (1987a). The infants were randomly assigned to one of two conditions: the 80% condition and the 50% condition. The infants in both conditions were habituated to a screen that rotated back and forth through a 180° arc. Following habituation, a box was placed behind the screen, and the infants saw two test events. In one (possible event), the screen rotated 112°, stopping when it reached the occluded box (see Figure 1). In the other event (impossible event), the screen continued to rotate after it reached the occluded box. For the infants in the 80% condition, the screen rotated 157° and thus rotated through the top 80% of the box. For the infants in the 50% condition, the screen rotated 135° and thus rotated through the top 50% of the box.

If the infants in the two conditions (a) represented, with reasonable accuracy, the height and location of the box behind the screen and (b) estimated, again with reasonable accuracy, the point at which the screen would reach the box, then they should be surprised in the impossible event when the screen continued rotating past this point. Since infants' surprise at an event typically manifests itself by prolonged attention to the event, the infants should look longer at the impossible than at the possible event. On the other hand, if the infants were poor at either (a) representing the box's height and location or (b) computing the screen's probable stopping point, then they

Figure 1. *Schematic representation of the habituation and test events shown to the infants in the 80% (left) and the 50% (right) conditions in Experiment 1.*



should fail to be surprised at the impossible event in both conditions or, at the very least, in the more difficult, 50% condition.

3.1. Method

3.1.1. Subjects

Subjects were 40 healthy, full-term infants ranging from 5 months, 17 days to 6 months, 28 days (M = 6 months, 9 days). An additional 3 infants were eliminated from the experiment, because of fussiness. The infants' names in this experiment and in the subsequent experiments were obtained from birth announcements in the local newspaper. Parents were contacted by letters and follow-up phone calls. They were offered reimbursement for their transportation expenses but were not compensated for their participation.

Half of the infants were assigned to the 80% condition, and half to the 50% condition.

3.1.2. Apparatus

The apparatus consisted of a large wooden box 120 cm high, 95 cm wide, and 68 cm deep. The infant faced an opening 49 cm high and 95 cm wide in the front wall of the apparatus. The interior of the apparatus was painted black and the floor was decorated with narrow pink and green stripes.

At the center of the apparatus was a silver cardboard screen 31 cm high, 28 cm wide, and 0.5 cm thick. The lower edge of the screen, which was set 0.5 cm above the floor of the apparatus, was affixed to a thick metal rod 28.5 cm long and 1 cm in diameter. This rod was connected to a right-angle gear box 2 cm high, 3.5 cm wide, and 4 cm deep. A drive rod 0.5 cm in diameter was also connected to the gear box. This rod was 54 cm long and protruded through the back wall of the apparatus. By rotating this rod, and experimenter could rotate the screen back and forth through a 180° arc. To help the experimenter rotate the screen at a constant pace, a protractor was attached to the drive rod. In addition, the experimenter listened through headphones to a metronome.

A wooden box 25 cm high, 15 cm wide, and 5 cm thick could be introduced into the apparatus through a hidden door in its back wall. This box was painted yellow and was decorated with a two-dimensional, brightly colored clown face. The box was placed on a platform 21 cm wide and 29 cm long in the floor of the apparatus behind the screen. This platform was mounted on a vertical slide located underneath the apparatus. By lowering the platform, after the screen occluded the box from the infant's view, an experimenter could surreptitiously remove the box from the path of the screen.

The infant was tested in a brightly lit room. Four clip-on lights (each with a 40-W lightbulb) were attached to the back and side walls of the apparatus to provide additional light. The lights were arranged so as to eliminate telltale shadows. Two wooden frames, each 183 cm high and 71 cm wide and covered with black cloth, stood at an angle on either side of the apparatus. These frames isolated the infant from the test room. Between trials, a muslin-covered frame 65 cm high and 95 cm wide was lowered in front of the opening in the front wall of the apparatus.

3.1.3. Events

Two experimenters worked in concert to produce the events; the first operated the screen and the second operated the platform.

80% condition events

Impossible test event. To start, the screen lay flat against the floor of the apparatus, toward the infant. The box stood clearly visible, centered 12.5 cm behind the screen. The first experimenter rotated the screen at the approximate rate of 45°/s until it had completed a 90° arc, at which point she paused for 1 s. This pause allowed the second experimenter to lower the platform supporting the box. The first experimenter then continued to rotate the screen toward the back wall at the same rate of about 45°/s until it had completed a 67.5° arc. The first experimenter held the screen in this position for 1 s, and then the entire process was repeated in reverse. The first experimenter returned the screen to the 90° position and paused for 1 s, allowing the second experimenter to raise the platform. The first experimenter then lowered the screen to its original position against the floor of the apparatus, revealing the box standing intact in the same position as before.

Each full cycle of movement thus lasted approximately 10 s. The box remained occluded for about 8 of these 10 s: it was in view only during the first and last seconds, when the screen was raised less than 45°. There was a 1 s pause between successive cycles. Cycles were repeated until the computer signaled that the trial had ended (see below). When this occurred, the second experimenter lowered the curtain in front of the apparatus.

Possible test event. The possible test event was identical to the impossible test event except that, instead of rotating the screen 67.5° toward the back wall and pausing for 1 s, the first experimenter rotated the screen 22.5° toward the back wall and paused for 2 s. Each full cycle of movement thus lasted approximately 9 s, with the box remaining occluded for about 7 of these 9 s.[1]

Habituation event. The habituation event was identical to the impossible test event with a few exceptions. First, the box was absent. Second, instead of rotating the screen 67.5° toward the back wall and pausing for 1 s, the first experimenter rotated the screen 90° and then reversed direction, without pausing. Each full cycle of movement thus lasted approximately 10 s, as in the impossible test event.

The platform was moved in the same manner in the habituation and impossible and possible test events to ensure that the faint sounds that accompanied

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[1]The 2-s pause in the possible event was introduced to make the rate of disappearance and reappearance of the box more similar in the two test events. With the pause, the occlusion time of the box was 8 out of 10 s in the impossible event and 7 out of 9 s in the possible event. Making these two figures highly similar helped ensure that (a) the infants could not discriminate between the two events on the basis of rate differences and (b) the two observers could not identify the events by the rate at which the platform was lowered and raised. Pilot data indicated that the two observers were unable to guess which event was being shown on the basis of the sounds associated with the movement of the platform.

the lowering and raising of the platform could not contribute to differences in the infants' looking times at the test events.

50% condition events
The habituation event and the impossible and possible test events shown to the infants in the 50% condition were identical to those shown to the infants in the 80% condition with one exception. Instead of rotating the screen 67.5° toward the back wall, in the impossible event, the first experimenter rotated the screen 45°, at the usual rate of 45°/s. Each full cycle of movement thus lasted approximately 9 s, as in the possible event.

3.1.4. Procedure
Prior to the beginning of the experiment, each infant was allowed to manipulate the box for a few seconds while his or her parent filled out consent forms. During the experiment, the infant sat on the parent's lap in front of the apparatus. The infant's head was approximately 65 cm from the screen and 100 cm from the back wall. The parent was asked not to interact with the infant while the experiment was in progress. At the start of the test trials, the parent was instructed to close his or her eyes.

The infant's looking behavior was monitored by two observers who viewed the infant through peepholes in the cloth-covered frames on either side of the apparatus. The observers could not see the experimental events, and they did not know the order in which the test events were presented. Each observer held a button box linked to a MICRO/PDP-11 computer and depressed the button when the infant attended to the experimental events. Inter-observer agreement was calculated for each trial on the basis of the number of seconds for which the observers agreed on the direction of the infant's gaze out of the total number of seconds the trial lasted. Disagreement of less than 0.1 s were ignored. Agreement in this experiment as well as in the subsequent experiments averaged 89% (or more) per trial per infant. The looking times recorded by the primary observer were used to determine when a trial had ended and when the habituation criterion had been met (see below).

Each infant participated in a three-phase procedure that consisted of a familiarization phase, a habituation phase, and a test phase. During the familiarization phase, each infant received a trial designed to acquaint him or her with the position of the box behind the screen. During this trial, the screen lay flat against the floor of the apparatus, with the box standing clearly visible behind it. The trial ended when the infant either (a) looked away from the display for 2 consecutive s after having looked at it for at least 10 cumulative s or (b) looked at the display for 30 cumulative s without looking away for 2 consecutive s.

Following the familiarization trial, each infant was habituated to the habituation event described above. The main purpose of this habituation phase was to acquaint the infant with the motion of the screen. Each habituation trial ended when the infant (a) looked away from the event for 2 consecutive s after having looked at it for at least 5 cumulative s or (b) looked at the event for 60 cumulative s without looking away for 2 consecutive s. The inter-trial interval was 2–3 s. Habituation trials continued until the infant either (a) reached a habituation criterion of a 50% or greater decrease in looking time on three consecutive trials, relative to the infant's looking time on the first three trials, or (b) completed nine habituation trials.

During the test phase, the infants in the two conditions saw the impossible and the possible test events described above on alternate trials until they had completed four pairs of test trials. Half of the infants in each condition saw the impossible event first, and half saw the possible event first. At the beginning of each test trial, the first experimenter waited to move the screen until the computer signaled that the infant had looked inside the apparatus for 2 cumulative s. This ensured that the infant had noted the presence of the box behind the screen. The criteria used to determine the end of each test trial were the same as for the habituation trials.

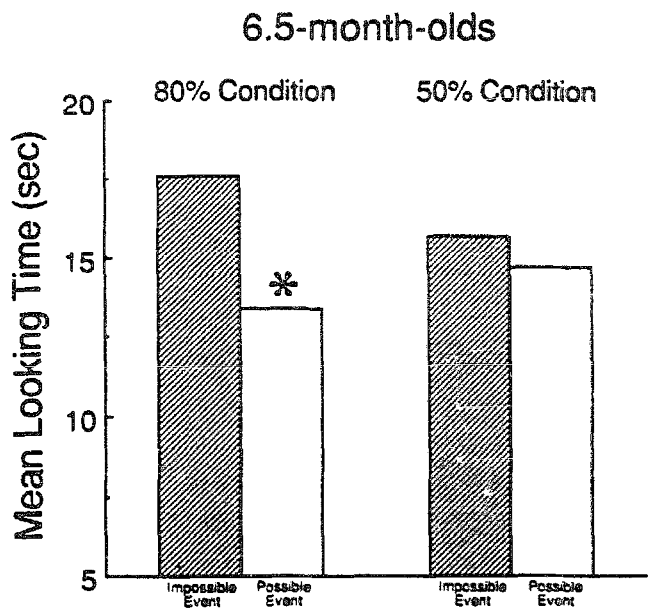
Ten of the 40 infants in the experiment completed fewer than four pairs of test trials. Seven of these infants completed only three pairs, 4 because the primary observer could not follow the direction of their gaze, 2 because of fussiness, and 1 because of straining. The other 3 infants completed only two pairs, because of fussiness. All subjects (in this experiment as well as in the subsequent experiments) were included in the data analyses, whether or not they had completed the full complement of four pairs of test trials.

3.2. Results

Figure 2 presents the mean looking times of the infants in the 80% and the 50% conditions at the test events. It can be seen that the infants in the 80% condition looked longer at the impossible than at the possible event, but that the infants in the 50% condition looked about equally at the two events.

The infants' looking times were analyzed by means of a $2 \times 2 \times 4$ mixed-model analysis of variance with condition (80% and 50% condition) as the between-subjects factor and with event (impossible or possible event) and test pair (first, second, third, or fourth pair of test trials) as the within-subjects factors. Because the design was unbalanced, the SAS GLM procedure was used to compute the analysis of variance (SAS Institute, 1985). Planned comparisons indicated that the infants in the 80% condition looked reliably longer at the impossible ($M = 17.6$) than at the possible ($M = 13.4$) event, $F(1, 240)$

Figure 2. *Mean looking times of the infants in the 80% and the 50% conditions in Experiment 1 at the impossible and the possible test events.*



= 4.10, $p < .05$, whereas the infants in the 50% condition looked about equally at the two events, $F(1, 240) = 0.23$ (impossible: $M = 15.7$, possible: $M = 14.7$).[2] There was also a significant effect of test pair, $F(3, 240) = 3.19$, $p < .05$, indicating that the infants looked reliably less as the experiment progressed.

Control condition

The infants in the 80% condition looked reliably longer at the impossible than at the possible test event, suggesting that they realized that the screen rotated farther than it should given the box's height and location. However, another interpretation of the infants' preference for the impossible event was

[2]The 50% condition's results were confirmed in a pilot study conducted with a procedure similar to that used by Baillargeon (1987b). In this study, 24 infants (M = 6 months, 9 days) were habituated to a screen rotating back and forth through a 180° arc. Following habituation, a box identical to that in Experiment 1 was placed behind the screen, and the infants watched two test events. In both events, the screen rotated back and forth through a 150° arc. The only difference between the events was in the orientation of the box behind the screen. In the possible event, the box lay flat 5.5 cm behind the screen and was 5 cm tall; in the impossible event, the box stood upright 18 cm behind the screen and was 25 cm tall. The 150° screen rotation was consistent with the horizontal but not with the vertical orientation of the box: in the latter case, the screen rotated through the top 58% of the space occupied by the box. The results indicated that the infants looked about equally at the impossible ($M = 23.3$) and at the possible ($M = 20.8$) events, $F(1, 107) = 0.98$.

that they found the 157° screen rotation intrinsically more interesting than the shorter, 112° rotation used in the possible event. To check this alternative interpretation, another group of 6.5-month-old infants was tested in a control condition that was identical to the 80% condition except that there was *no box* behind the screen during the test events.

Subjects were 20 full-term infants ranging in age from 6 months, 1 day to 6 months, 28 days (M = 6 months, 12 days). Three infants completed only three test pairs, 2 because the primary observer could not follow the direction of their gaze and 1 because of fussiness. Two other infants completed only two pairs, because of fussiness.

The looking times of the infants in the 80% and the control conditions were compared by means of a 2 × 2 × 4 mixed-model analysis of variance with condition (80% or control condition) as the between-subjects factor and with event (impossible/157° or possible/112° event) and test pair (first, second, third, or fourth test pair) as the within-subjects factors. There was a significant Condition × Event interaction, $F(1, 240) = 6.12$, $p < .05$. Follow-up comparisons confirmed that the infants in the 80% condition looked reliably longer at the impossible ($M = 17.6$) than at the possible ($M = 13.4$) event, $F(1, 240) = 5.19$, $p < .05$, whereas the infants in the control condition tended to look equally at the 157° ($M = 11.7$) and the 112° ($M = 13.9$) events, $F(1, 240) = 1.40$, $p > .05$. This last finding provides evidence that the infants in the 80% condition looked reliably longer at the impossible event, not because they found the 157° rotation more interesting than the 112° rotation, but because they realized that the screen rotated farther than it should given the height and location of the occluded box.

3.3. *Discussion*

The infants in the 80% condition looked reliably longer at the impossible than at the possible event, whereas the infants in the 50% condition looked about equally at the two events. These results suggest that 6.5-month-old infants are able to represent and to reason quantitatively about the height and location of an occluded object, but that their ability to do so is sharply limited. The infants in the experiment realized that the screen rotated farther than it should when it rotated through the top 80%, but not the top 50%, of the occluded box. To adults, the 50% violation is less extreme than the 80% violation, but is still obvious. Why did the infants fail to perceive that the 135° rotation, like the 157° rotation, was inconsistent with the height and location of the occluded box? Perhaps the infants were unable to precisely estimate the point at which the screen should reach the box because (a) their representation of the box's height and location was too poor and/or (b) their ability to compute the screen's stopping point was too limited.

Experiment 2 examined whether 4.5-month-old infants, like 6.5-month-old infants, possess at least a rudimentary ability to represent and to reason quantitatively about the height and location of an occluded object. The infants were tested in exactly the same manner as the infants in the 80% condition in Experiment 1.

4. Experiment 2

4.1. Method

4.1.1. Subjects

Subjects were 20 healthy, full-term infants ranging in age from 3 months, 29 days to 4 months, 25 days (M = 4 months, 13 days).

4.1.2. Apparatus, events, and procedure

The apparatus, events, and procedure in Experiment 2 were identical to those in the 80% condition in Experiment 1. Two infants completed only three test pairs, because the primary observer could not follow the direction of their gaze. Four other infants completed only two pairs, because of fussiness.

4.2. Results

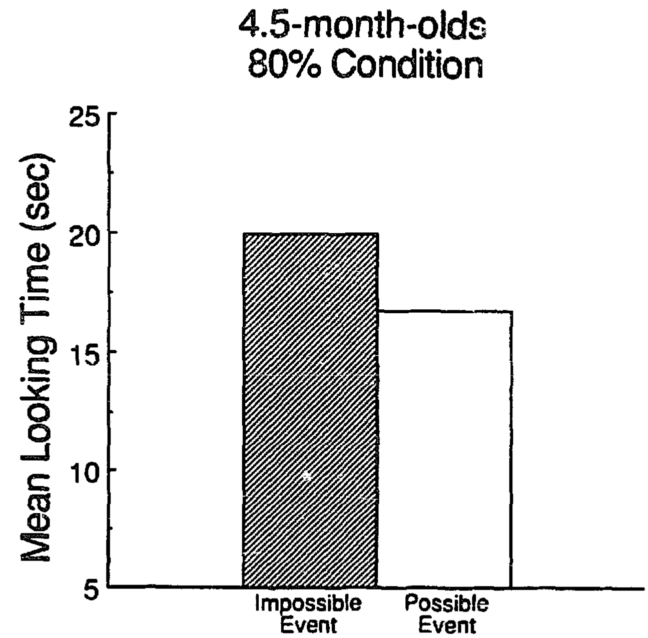
Figure 3 presents the infants' mean looking times at the test events. It can be seen that the infants tended to look longer at the impossible than at the possible event.

The infants' looking times were analyzed by means of a 2 × 4 mixed-model analysis of variance with event (impossible or possible event) and test pair (first, second, third, or fourth test pair) as the within-subjects factors. The main effect of event was not significant, $F(1, 113) = 1.48$, $p > .20$, indicating that the infants' preference for the impossible (M = 19.9) over the possible (M = 16.7) event was not reliable. No other effect was significant.

4.3. Discussion

The 4.5-month-old infants in Experiment 2 did not look reliably longer at the impossible than at the possible event, suggesting that they perceived both the

Figure 3. *Mean looking times of the infants in Experiment 2 at the impossible and the possible test events.*



157° and the 112° screen rotations as consistent with the box's height and location.[3]

Together, the results of Experiments 1 and 2 and those of Baillargeon (1987a) reveal an interesting developmental sequence. Specifically, when a box 25 cm high is placed 12.5 cm behind a rotating screen, 6.5-month-old

[3]There was some concern about accepting this conclusion because (a) the 4.5-month-olds' data seemed only slightly weaker than those obtained with the 6.5-month-olds in the 80% condition in Experiment 1 (the mean looking times of the younger infants at the impossible and possible events were 19.9 and 16.7, and those of the older infants, 17.6 and 13.4) and (b) the p-values reported in the two experiments were obtained using different analyses (the 4.5-month-olds' data were analyzed alone whereas the 6.5-month-olds' data were analyzed with the 50% condition or with the control condition data). However, further analyses indicated that this concern was misplaced. First, the looking times of the 6.5-month-olds in the 80% condition in Experiment 1 were analyzed like those of the 4.5-month-olds in Experiment 2, using a 2 × 4 analysis of variance with event and test pair as within-subject factors. This analysis yielded a reliable main effect of event, $F(1, 121) = 4.02$, $p < .05$, confirming that the 6.5-month-olds looked reliably longer at the impossible than at the possible event. Second, the looking times of the 4.5-month-olds in Experiment 2 were compared with those of 20 4.5-month-olds (M = 4 months, 16 days) tested in a control (no box) condition identical to that in Experiment 1. The data were analyzed as in Experiment 1. The interaction between condition and event was not reliable, $F(1, 228) = 0.01$, nor was any effect involving condition as a factor. There was thus no reliable difference between (a) the looking times of the 4.5-month-olds in Experiment 2 at the impossible (M = 19.9) and the possible (M = 16.7) events and (b) the looking times of the 4.5-month-olds in the control condition at the 157° (M = 16.9) and the 112° (M = 14.2) events. These results contrast sharply with those obtained with the 6.5-month-olds in Experiment 1: recall that the looking times of the infants in the 80% and the control conditions were found to be reliably different.

infants are surprised to see the screen rotate through the top 80%, but not the top 50%, of the box. In contrast, 4.5-month-old infants are surprised to see the screen rotate through the entire (100%) box, but not the top 80% of the box. Another way of stating this sequence is that, at 4.5 months of age, infants are capable of detecting 100% violations, and at 6.5 months of age, 80% violations. Presumably, by testing older subjects, one could identify the age at which infants become capable of detecting 50% violations.

Several alternative explanations can be offered for the developmental sequence just described; they are discussed in the conclusion section.

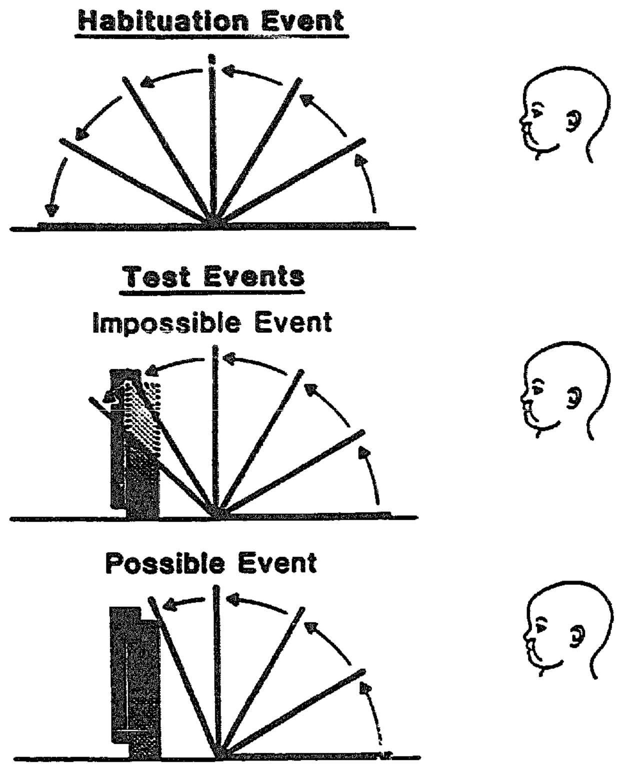
5. Experiment 3

The results of Experiment 1 indicated that 6.5-month-old infants' ability to represent and to reason quantitatively about the height and location of an occluded object is limited. The infants' estimation of when the screen would reach the box was so unprecise that they regarded both the 112° and the 135° rotations as acceptable stopping points for the screen – failing to realize that, in the latter case, the screen rotated through the top half of the space occupied by the box.

Could one identify conditions under which infants would form more precise expectations as to the screen's stopping point? Experiment 3 attempted to address this question. The method of Experiment 3 was identical to that of the 50% condition in Experiment 1 with one exception: a second, identical box was placed to the right of the box behind the screen (see Figure 4). This second box stood out of the screen's path and so remained visible throughout the familiarization and test trials.

There were at least two different ways in which the visible box could enhance the performance of the infants in Experiment 3. On the one hand, it provided a reminder of the occluded box's height and location. If the infants in the 50% condition in Experiment 1 failed to show surprise at the impossible event because their representation of the box's height and location was too poor to allow them to precisely estimate when the screen would reach the box, then reminding the infants of the box's height and location should alleviate this difficulty. On the other hand, the visible box enabled the infants to use an alternative, easier approach to the task of predicting the screen's stopping point. Consider what adults would do in this situation: they would expect the screen to stop when its top edge was in the same fronto-parallel plane as the top of the visible box; if the screen rotated past this point by a significant amount (as it did in the 50% condition), they would infer trickery. If the infants in the 50% condition in Experiment 1 failed to be surprised at

Figure 4. *Schematic representations of the habituation and test events shown to the infants in Experiment 3.*



the impossible event not because their representation of the box's height and location was too vague but because their computation of the screen's stopping point was too imprecise, then providing the infants with an alternative, easier way of determining this stopping point should circumvent this difficulty. (It should be noted that in this alternative approach the task of predicting where the screen should stop is not a quantitative but a qualitative one. As long as the occluded and the visible boxes are of the same height and are located in the same fronto-parallel plane, one can predict the screen's stopping point by aligning the screen and the visible box without concerning oneself with the boxes' actual height and location.)

5.1. Method

5.1.1. Subjects

Subjects were 20 healthy, full-term infants ranging in age from 5 months 28 days to 6 months 27 days (M = 6 months, 16 days). An additional 3 infants were eliminated from the experiment, because of fussiness.

5.1.2. Apparatus, events, and procedure

The apparatus, events, and procedure in this experiment were identical to those in the 50% condition in Experiment 1 with one exception. During the familiarization and test trials, a second, identical box was placed 10 cm to the right of and in the same fronto-parallel plane as the box behind the screen. One infant completed only three test pairs, because of fussiness.

5.2. Results

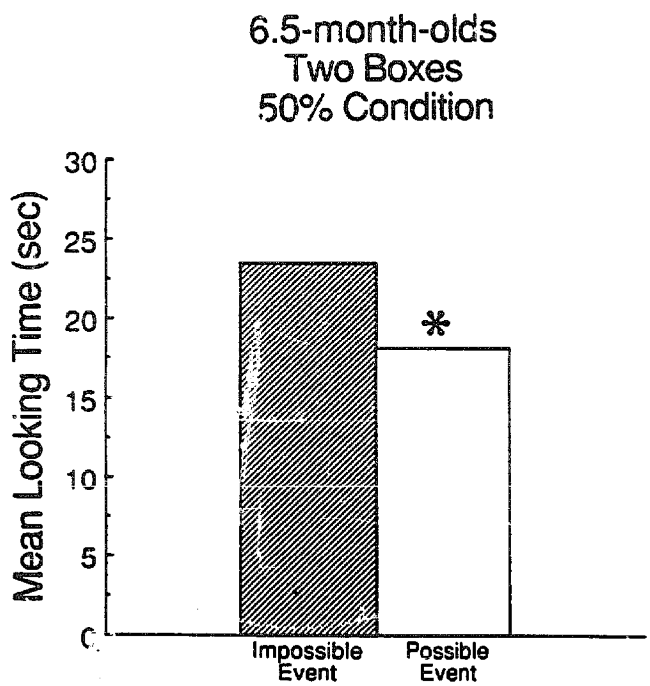
Figure 5 shows the infants' mean looking times at the two test events. It can be seen that the infants looked longer at the impossible than at the possible event.

The results were analyzed as in Experiment 2. There was a significant main effect of event, $F(1, 75) = 8.32$, $p < .01$, indicating that the infants looked reliably longer at the impossible ($M = 23.5$) than at the possible ($M = 18.1$) event. No other effect was significant.

Control condition

The infants in Experiment 3 looked reliably longer at the impossible than

Figure 5. *Mean looking times of the infants in Experiment 3 at the impossible and the possible test events.*



at the possible event, suggesting that they (a) made use of the visible box to determine at what point the screen would contact the occluded box and (b) were surprised when the screen continued rotating past this point. However, there was another interpretation for the results of Experiment 3. The infants could have looked longer at the impossible event simply because they preferred the event in which the screen rotated *past* the top of the visible box to the event in which the screen rotated *until* it reached the visible box. In other words, the infants could have forgotten or dismissed the presence of the occluded box and focused exclusively on the interaction of the screen and the visible box. To check this interpretation, another group of 6.5-month-old infants was run in a control condition that was identical to Experiment 3 except that *no box* was placed behind the screen. Only the second box was present, standing as before to the side of the screen.

Subjects were 20 healthy, full-term infants ranging in age from 6 months, 0 days to 6 months, 26 days (M = 6 months, 13 days). An additional 5 infants were eliminated, 3 because of fussiness and 2 because of experimenter error. Eight infants completed only three test pairs, 7 because of fussiness and 1 because of drowsiness. Three other infants completed only two pairs, because of fussiness.

The looking times of the infants in Experiment 3 and in the control condition were analyzed as in Experiment 1. There was a significant main effect of event, $F(1,137) = 4.07$, $p < .05$, and a significant Condition × Event interaction, $F(1,137) = 4.24$, $p < .05$. Follow-up comparisons confirmed that the infants in Experiment 3 looked reliably longer at the impossible (M = 23.5) than at the possible (M = 18.1) event, $F(1,137) = 9.86$, $p < .005$, whereas the infants in the control condition tended to look equally at the 135° (M = 15.9) and the 112° (M = 15.6) events, $F(1,137) = 0.02$. This last result provides evidence that the infants in Experiment 3 looked reliably longer at the impossible event, not because they preferred to see the screen rotate past the top of the visible box, but because they were surprised that the screen failed to stop when it reached the occluded box.

5.3. Discussion

Unlike the 6.5-month-old infants in the 50% condition in Experiment 1, the 6.5-month-old infants in Experiment 3 looked reliably longer at the impossible than at the possible event. Together, these results suggest that the infants in Experiment 3 did make use of the visible box: they detected with it a violation they failed to detect without it.

6. Experiment 4

The 4.5-month-old infants in Experiment 2 failed to show surprise when the screen rotated through the top 80% of the space occupied by the box, as though they perceived both the 157° (impossible event) and the 112° (possible event) rotations to be acceptable stopping points for the screen. Experiment 4 tested whether 4.5-month-old infants, like 6.5-month-old infants, could take advantage of a second, identical box placed to the side of the box behind the screen to estimate more precisely where the screen should stop. One group of infants (80%/box condition) was tested using the same procedure as in Experiment 2 except that a second box was placed next to the first, as in Experiment 3. Another group of infants (50%/box condition) was tested using the same procedure as in Experiment 3. Experiment 4 thus examined whether 4.5-month-old infants could detect the 80% and the 50% screen violations when the second box was present.

6.1. Method

6.1.1. Subjects

Subjects were 40 healthy, full-term infants ranging in age from 4 months, 2 days to 4 months, 25 days (M = 4 months, 13 days). An additional 9 infants were eliminated from the experiment, because of fussiness. Half of the infants were assigned to the 80%/box condition, and half to the 50%/box condition.

6.1.2. Apparatus, events, and procedure

80%/box condition

The apparatus, events, and procedure used in the 80%/box condition in Experiment 4 were identical to those in Experiment 2 with one exception. During the familiarization and test trials, a second, identical box was placed 10 cm to the right of and in the same fronto-parallel plane as the box behind the screen. This second box stood out of the screen's path and so remained visible throughout the trials.

Four infants completed only three test pairs, 3 because of fussiness and 1 because the primary observer could not follow the direction of the infant's gaze. Three other infants completed only two pairs, because of fussiness.

50%/box condition

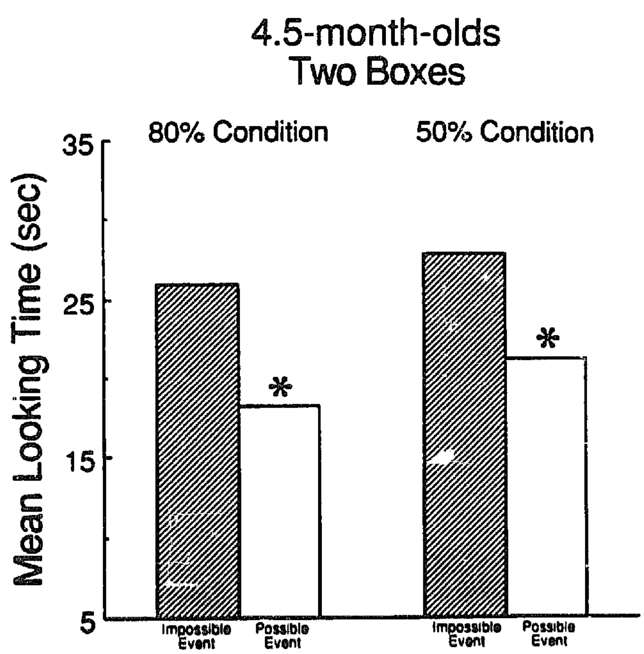
The apparatus, events, and procedure used in the 50%/box condition were identical to those in Experiment 3. Five infants completed only three test pairs, 4 because of fussiness and 1 because of procedural error. Four other infants completed only two pairs, because of fussiness.

6.2. *Results*

Figure 6 shows the mean looking times of the infants in the 80%/ and the 50%/box conditions at the test events. It can be seen that the infants in both conditions looked longer at the impossible than at the possible event.

The infants' looking times were analyzed as in Experiment 1. Planned comparisons indicated that (a) the infants in the 80%/box condition looked reliably longer at the impossible (M = 26.0) than at the possible (M = 18.2) event, $F(1, 129) = 10.84$, $p < .005$, and (b) the infants in the 50%/box condition looked reliably longer at the impossible (M = 27.8) than at the possible (M = 21.2) event, $F(1, 129) = 7.58$, $p < .01$). Consistent with these results, the analysis of variance yielded a significant main effect of event, $F(1, 129) = 21.34$, $p < .00001$, showing that the infants looked reliably longer overall at the impossible (M = 26.9) than at the possible (M = 19.7) event.

Figure 6. *Mean looking times of the infants in the 80%/box and the 50%/box conditions in Experiment 4 at the impossible and the possible test events.*



Control conditions

The infants in both the 80%/box and the 50%/box conditions in Experiment 4 looked reliably longer at the impossible than at the possible event. These results suggest that the infants (a) used the visible box to predict at what point the screen would reach the occluded box and (b) were surprised to see the screen rotate past this point. However, another interpretation for the results of Experiment 4 was that the infants looked longer at the impossible event simply because they preferred to see the screen rotate past the edge of the visible box. To check this alternative interpretation, two additional groups of infants were tested in control conditions that were identical to the 80%/box and the 50%/box conditions in Experiment 4 except that *no box* was placed behind the screen. Only the second box, to the side of the screen, remained in the apparatus.

Subjects were 40 healthy, full-term infants ranging in age from 4 months, 0 days to 4 months, 25 days (M = 4 months, 14 days). An additional 7 infants were eliminated from the experiment, 6 because of fussiness and 1 because of drowsiness. Half of the infants were assigned to the control 80%/box condition, and half to the control 50%/box condition. Eleven infants completed only three test pairs, 7 because of fussiness, 2 because of drowsiness, and 2 because the primary observer could not follow the direction of their gaze. Two other infants completed only two pairs, because of fussiness.

The looking times of the infants in the 80%/box condition and the control 80%/box condition were analyzed as in Experiment 3. There was a significant Condition × Event interaction, $F(1, 133) = 8.82$, $p < .005$. Follow-up comparisons indicated that the infants in the 80%/box condition looked reliably longer at the impossible ($M = 26.0$) than at the possible ($M = 18.2$) event, $F(1, 133) = 11.56$, $p < .001$, whereas the infants in the control condition tended to look equally at the 157° ($M = 20.6$) and the 112° ($M = 22.6$) events, $F(1, 133) = 0.81$.

Comparison of the looking times of the infants in the 50%/box condition and the control 50%/box condition yielded a significant main effect of event, $F(1, 133) = 5.03$, $p < .05$, and a significant Condition × Event interaction, $F(1, 133) = 7.91$, $p < .01$. Follow-up comparisons indicated that the infants in the 50%/box condition looked reliably longer at the impossible ($M = 27.8$) than at the possible ($M = 21.2$) event, $F(1, 133) = 9.04$, $p < .005$, whereas the infants in the control condition tended to look equally at the 135° ($M = 18.6$) and the 112° ($M = 19.3$) events, $F(1, 133) = 0.10$.

The results of these two control conditions provide evidence that the infants in the 80%/box and the 50%/box conditions in Experiment 4 looked reliably longer at the impossible event, not because they preferred to see the screen rotate past the top of the visible box, but because they realized that the screen failed to stop when it contacted the occluded box.

6.3. *Discussion*

The infants in the 80%/box and the 50%/box conditions in Experiment 4 looked reliably longer at the impossible than at the possible event. These results indicate that the infants did make use of the visible box: they detected with it violations that, as shown in Experiment 2, they could not detect without it.

7. Experiment 5

The 6.5- and 4.5-month-old infants in Experiments 3 and 4 were able to make use of the visible box placed to the side of the occluded box to predict at what point the screen would stop. How did the visible box facilitate the infants' performance? Two possibilities, mentioned earlier, are that (a) the visible box served to remind the infants of the height and location of the occluded box, allowing them to compute more precisely the screen's stopping point, and (b) the visible box provided the infants with an alternative, easier way of estimating the screen's stopping point, by aligning the screen with the top of the visible box. Which of these two hypotheses best describes the role played by the visible box? Experiments 5 and 6 began to address this question. Groups of 6.5- and 4.5-month-old infants were tested using the same procedures as in Experiments 3 and 4 except that the second box was no longer placed in the same fronto-parallel plane as the box behind the screen. The second box now stood to the right and *in front* of the box behind the screen. The screen thus rotated past the top of the second box in both the possible and the impossible events.

Evidence that the infants performed as well when the second box stood in front of or next to the box behind the screen would contradict the hypothesis that the infants in Experiments 3 and 4 expected the screen to stop when it was aligned with the top of the second box. Instead, such evidence would support the hypothesis that the infants in these experiments performed successfully because the second box reminded them of the occluded box's height and location, enabling them to more precisely compute the screen's stopping point. On the other hand, evidence that the infants performed poorly when the second box stood in front of the box behind the screen would provide support for the hypothesis that the infants in Experiments 3 and 4 used the top of the second box as a reference point to estimate the screen's stopping point.

7.1. Method

7.1.1. Subjects

Subjects were 20 healthy, full-term infants ranging in age from 5 months, 27 days to 7 months, 1 day (M = 6 months, 13 days).

7.1.2. Apparatus, events, and procedure

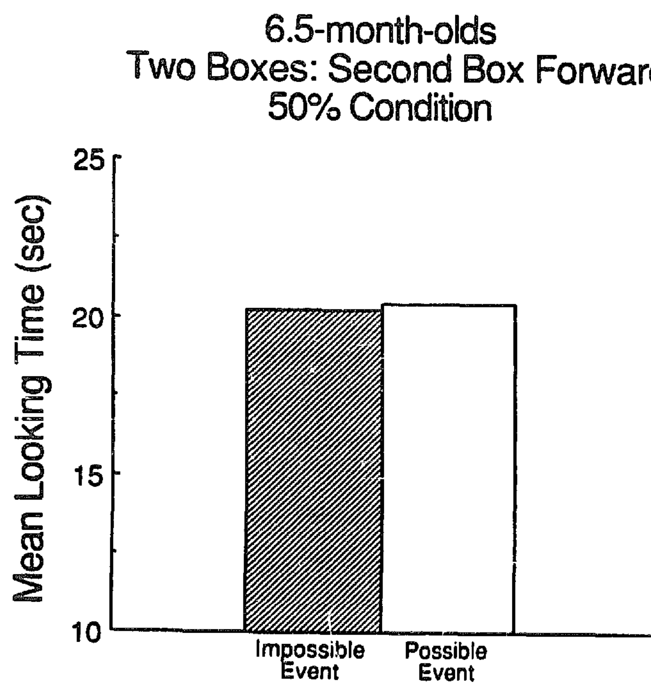
The apparatus, events, and procedure used in Experiment 5 were identical to those in Experiment 3 except that the second box stood 10 cm to the right and 8.5 cm in front of the box behind the screen (since the second box was 5 cm thick, the distance between the back of this box and the front of the box behind the screen was 3.5 cm). The screen rotated past the top 62% of the second box in the 112° event, and past the top 84% of the box in the 135° event.

One infant completed only three test pairs, because of procedural error, and another infant completed only two pairs, because of equipment failure.

7.2. Results

Figure 7 shows the infants' mean looking times at the test events. It can be seen that they looked about equally at the 135° and the 112° events.

Figure 7. *Mean looking times of the infants in Experiment 5 at the impossible and the possible test events.*



The results were analyzed as in Experiment 3. The main effect of event was not significant, $F(1, 19) = 0.02$, indicating that the infants tended to look equally at the 135° ($M = 20.2$) and the 112° ($M = 20.4$) events. The only significant effect was that of test pair, $F(3, 108) = 3.72$, $p < .05$, showing that the infants looked reliably less as the experiment progressed.

The results of Experiment 5 will be discussed together with those of Experiment 6.

8. Experiment 6

Experiment 6 was identical to Experiment 4 except that, as in Experiment 5, the second box was placed to the right and in front of the box behind the screen.

8.1. Method

8.1.1. Subjects

Subjects were 20 healthy, full-term infants ranging in age from 4 months, 0 day to 4 months, 27 days (M = 4 months, 14 days). One additional infant was eliminated from the experiment, because of fussiness.

Half of the infants were assigned to the 80%/box-forward condition, and half to the 50%/box-forward condition.

8.1.2. Apparatus, events, and procedure

The apparatus, events, and procedure used in Experiment 6 were identical to those in Experiment 4 except that, as in Experiment 5, the second box was placed 10 cm to the right and 8.5 cm in front of the box behind the screen. For the infants in the 50%/box-forward condition, the screen rotated past the top 62% and the top 84% of the second box in the 112° and the 135° events, respectively; for the infants in the 80%/box-forward condition, the screen rotated past the top 62% and the top 93% of the second box in the 112° and the 157° events, respectively.

Four infants completed only three test pairs, 2 because the primary observer could not follow the direction of their gaze, 1 because of fussiness, and 1 because of procedural error. One other infant completed only two pairs, because of fussiness.

8.2. Results

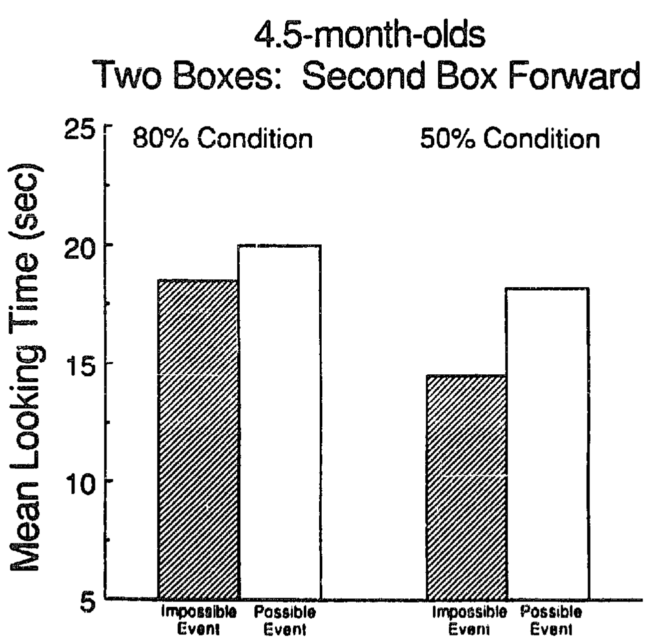
Figure 8 shows the mean looking times of the infants in the 80%/box-forward and the 50%/box-forward condition at the test events. It can be seen that both groups of infants looked about equally at the events.

The infants' looking times were analyzed as in Experiment 4. Planned comparisons indicated that (a) the infants in the 80%/box-forward condition looked about equally at the 157° (M = 18.5) and the 112° (M = 20.0) events, $F(1, 114) = 0.19$, and (b) the infants in the 50%/box-forward condition looked about equally at the 135° (M = 14.5) and the 112° (M = 18.2) events, $F(1, 114) = 1.14$, $p > .05$.

8.3. Discussion

Unlike the infants in Experiments 3 and 4, the infants in Experiments 5 and 6 were unable to detect when the screen rotated farther than it should. These results indicate that the infants in these experiments could make use of the second box only when it stood *next to* the box behind the screen; the infants' performance was as poor when the second box was placed *in front* of the box behind the screen as when the second box was absent altogether (cf. Experiments 1 and 2).

Figure 8. *Mean looking times of the infants in the 80%/box-forward and the 50%/box-forward conditions in Experiment 5 at the impossible and the possible test events.*



Two explanations were offered earlier for the successful performance of the infants in Experiments 3 and 4. One was that the second box reminded the infants of the height and location of the occluded box, allowing them to more precisely compute the screen's stopping point. The other was that the second box enabled the infants to use an easier, qualitative strategy for predicting the screen's stopping point, by aligning the screen with the top of the second box. The results of Experiments 5 and 6 provide evidence for the second of these explanations. Moving the second box forward made it impossible for the infants to employ an alignment strategy, but still gave them information about the occluded box's height and location. The infants' unsuccessful performance suggests that they were unable to put this information to good use.

It might be argued that the infants in Experiments 5 and 6 performed less well than the infants in Experiments 3 and 4, not because they could not use an alignment strategy, but because the information available to them about the occluded box's height and location was not as effective. The second box might have constituted a better reminder of the occluded box's height and location when placed next to, as opposed to in front of, the occluded box. Although logically possible, this proposal seems rather unlikely. Recent experiments reveal that infants aged 4.5 months and older have sufficient depth perception and size constancy to apprehend and compare the height and location of the two boxes used in the experiments, regardless of their positions in the apparatus (e.g., Granrud, in press; Yonas & Granrud, 1985). It is difficult to imagine why infants would have more difficulty remembering that a box is a few centimeters away from a second box along a diagonal as opposed to a side path.

9. General discussion

The 6.5- and 4.5-month-old infants in Experiments 1 and 2 were habituated to a screen that rotated through a 180° arc. Following habituation, a box 25 cm tall was centered 12.5 cm behind the screen, and the infants saw a possible and an impossible test event. In the possible event, the screen stopped rotating when it reached the occluded box; in the impossible event, the screen rotated through a portion of the space occupied by the occluded box. The results indicated that (a) the 6.5-month-old infants looked reliably longer at the impossible event when the screen rotated through the top 80%, but not the top 50%, of the box and (b) unlike the 6.5-month-old infants, the 4.5-month-old infants did not look longer when the screen rotated through the top 80% of the box. Thus, 4.5-month-old infants show surprise only when the screen rotates through the entire (100%) space occupied by the box (Baillargeon, 1987a).

In Experiments 3 and 4, a second, identical box was placed to the side of the box behind the screen, out of the screen's path. With the introduction of this second box, (a) the 6.5-month-old infants looked reliably longer when the screen rotated through the top 50% of the occluded box and (b) the 4.5-month-old infants looked reliably longer when the screen rotated through the top 80% as well as the top 50% of the occluded box. The results of Experiments 5 and 6 indicated that the improvements in the infants' performances brought about by the addition of the second box disappeared when this second box was placed next to and in front of the box behind the screen.

How can one describe the physical reasoning abilities revealed by these experiments? Several developmental models could be offered; two are briefly described. According to the *first* model, infants have available two different strategies for predicting when the rotating screen should reach the occluded box and stop. One strategy (direct estimation strategy) is used when only the box behind the screen is present; the task of predicting the screen's stopping point is then a quantitative one, requiring infants to represent and to reason about the occluded box's height and location. Exactly what this quantitative strategy consists of is as yet unclear. Perhaps infants mentally simulate the rotation of the screen and its contact with the occluded box and then compare the screen's predicted and real stopping points; or perhaps infants keep in their mind's eye an image of the box as it stands behind the screen and expect the screen to stop when it reaches this imaginary box.

The second strategy (referential estimation strategy) for determining the screen's stopping point is used when the second box is placed next to the box behind the screen. This second, visible box is treated as a reference point: it is assumed that the screen will reach the top of the occluded box and stop when it is aligned with the top of the visible box. With this strategy, the task of estimating the screen's stopping point becomes a qualitative one since there is no need to represent the occluded box's actual height and location: provided that the occluded and the visible boxes are of identical height and are placed in the same fronto-parallel plane, one can rely on the alignment to yield a correct solution.

According to the first model, young infants are capable of using both the direct and the referential estimation strategies for predicting the screen's stopping point, although they perform distinctly better with the former than with the latter strategy (given the nature of the two strategies, it is not surprising that the referential estimation strategy should yield more accurate responses than the direct estimation strategy). With the direct estimation strategy, 6.5-month-old infants are able to detect 80% violations and 4.5-

month-old infants, 100% violations; with the referential estimation strategy, 6.5-month-old infants are able to detect 50% violations and 4.5-month-old infants, 80% and 50% violations.

These results suggest two further comments. One is that the improvement in infants' use of the direct estimation strategy (from 100% violations at 4.5 months to 80% violations at 6.5 months) could reflect, as was mentioned above, (a) a more accurate representation of the occluded box's height and location and/or (b) a more precise computation of the angle at which the screen should reach the occluded box. The other comment is that, although the present data did not reveal developmental differences in infants' use of the referential estimation strategy, such differences do exist. In a recent experiment, the perceptual similarity of the visible and the occluded boxes was systematically varied and was either *high* (a red box with white dots and a red box with green dots), *moderate* (a red box with white dots and a yellow box with green dots), or *low* (a red box with white dots and a yellow box with a clown face). The results indicated that (a) the 6.5-month-old infants detected 50% violations when the similarity between the visible and the occluded boxes was high or moderate but not when it was low and (b) the 4.5-month-old infants detected 50% violations only when the similarity between the boxes was high. These results suggest that with age infants become better at dismissing irrelevant differences in objects that are used as reference points in solving physical problems (Baillargeon, 1990, in press).

The second model to be considered is identical to the first with one important exception: it holds that 6.5-month-old infants are capable of using both the direct and the referential estimation strategy, but that 4.5-month-old infants are capable of using only the latter strategy. According to this model, 4.5-month-old infants detect 100% violations with a single box present, not by a (very rudimentary) direct estimation strategy, but by another type of qualitative, referential strategy. Specifically, infants take the apparatus's floor as their point of reference: they reason that if the screen rotates 180° until it lies flat against the apparatus's floor, then it has rotated farther than it should have, given the presence of the box in its path. The interest of this second model relative to the first is that it hints at a potentially important development between 4.5 and 6.5 months of age, namely, the emergence of quantitative physical reasoning. Whereas 6.5-month-old infants would be capable of representing and reasoning about specific quantities in solving physical problems, 4.5-month-old infants would be limited to representing and reasoning about equalities and inequalities.

Both of the models proposed above assume that, at least by 6.5 months of age, infants go about predicting the screen's stopping point very differently when one box is present and when two identical boxes, placed side by side, are present. In the former case, infants are said to reason quantitatively, and in the latter case, qualitatively. How valid is this assumption? It might be suggested that the infants in the present experiments reasoned qualitatively even when only one box was present, using as their reference point some mark on the apparatus's walls. On this view, infants would perform better with two boxes than with one because the second box would provide a clearer, easier cue than a more distant wall mark. Though possible, this alternative is unlikely. The walls of the apparatus were painted a uniform black, making it virtually impossible to isolate potential referential cues. Additional evidence against this hypothesis comes from the finding that infants do not use the second box when its appearance is very different from that of the box behind the screen (Baillargeon, 1990, in press).

Alternatively, it might be argued that the infants in the present experiments always reasoned quantitatively about the screen's stopping point and performed better when the second box was placed to the side of the box behind the screen because they then had at their disposal more accurate information about the screen's position. That is, it might be proposed that the infants had difficulty, perhaps because of limited depth perception, judging exactly how far the screen had rotated before it stopped. The second box could have given the infants an anchor against which to judge the extent of the screen's movement. However, there are again reasons to question this interpretation. Recent research on young infants' depth perception (e.g., Granrud, in press; Yonas, Arterberry, & Granrud, in press; Yonas & Granrud, 1985) suggests that the infants in the present experiments had adequate depth perception to judge the screen's angle of rotation. Furthermore, the finding that infants do not make use of the second box when its appearance differs markedly from that of the box behind the screen (Baillargeon, 1990) contradicts the idea that the second box merely provides information about the screen's angle of rotation since this information is present regardless of the second box's appearance.

A third alternative interpretation for the present results is that the infants always reasoned quantitatively about the screen's stopping point but performed better when the second box stood next to the occluded box because the second box gave them more accurate information about the occluded box's height and location. As was discussed earlier, the finding that the infants' performance deteriorated when the second box was moved a few centimeters in front of the occluded box provides strong (though admittedly not conclusive) evidence against this interpretation: it is implausible that the information provided by the second box when standing next to, or next to and slightly in front of, the occluded box, was radically different (recall that only 3.5 cm separated the back of the second box from the occluded box).

A fourth alternative interpretation for the present results is that the infants engaged in neither qualitative nor quantitative reasoning. Instead of attempting to predict the screen's stopping point, the infants could have focused their attention on the box behind the screen and been surprised when the screen's rotation revealed space previously filled by the box to be empty. On this view, the infants performed better with the second box (Experiment 3 and 4) because it reminded them of the exact portions of space filled by the occluded box. None of the results presented above provides evidence against this interpretation. Such evidence does exist, however, and comes from data collected with 4.0- to 6.5-month-old infants using several different experimental paradigms (Baillargeon, 1986; Baillargeon & DeVos, 1990; Baillargeon et al., 1990). The infants in these various experiments watched impossible events that differed superficially but all involved an object moving through the space occupied by an obstacle. These events took place behind screens so that the infants did not see the space occupied by the obstacle alternately full and empty. Nevertheless, the infants in the experiments looked reliably longer at the impossible than at the possible events they were shown, indicating that they expected the moving object to stop against the obstacle and were surprised that it did not. To illustrate, in one series of experiments (Baillargeon, 1986; Baillargeon & DeVos, 1990), 4.0- and 6.5-month-old infants sat in front of a small screen; to the left of the screen was a long, inclined ramp. The infants were habituated to the following event: the screen was raised (to show the infants that there was nothing behind it) and lowered, and a toy car rolled down the ramp, passed behind the screen, and exited the apparatus to the right. The test events were identical to the habituation event exept that a toy (e.g., a large Mickey Mouse doll) stood behind the screen, either on top (impossible event) or in back (possible event) of the car's tracks. This toy was revealed when the screen was raised. The infants looked reliably longer at the impossible than at the possible event, indicating that they expected the car to stop against the toy and were surprised that it did not. Given these findings, parsimony suggests that the present results are unlikely to be caused by the infants' puzzlement at seeing the same spatial locations alternately full and empty.

The results of the experiments reported here indicate that young infants' ability to reason about physical events is far more sophisticated than has traditionally been assumed. Indeed, the present results suggest that young infants have a repertoire of physical reasoning strategies, some quantitative and others qualitative, and spontaneously shift from the use of one strategy to another depending on the specific context in which a problem is presented to them. Further research will hopefully shed light on the nature, origins, and development of these strategies, thereby contributing to the elaboration of a theory of physical reasoning in infancy.

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