British Journal of Developmental Psychology (1994), 12, 9–33 *Printed in Great Britain*

Physical reasoning in young infants: Seeking explanations for impossible events

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There is now considerable evidence that infants are surprised when shown impossible events that violate their beliefs about objects, as indexed by reliably greater looking times at these events than at possible events that are consistent with their beliefs. Do infants also attempt, as older children and adults do, to generate explanations for these impossible events? Data from our laboratory provide intriguing hints that infants, like older children and adults, strive to reconcile what they observe with what they believe. This evidence comes from experiments in which infants were presented with an impossible and a possible event and were found *not* to show the typical preference for the impossible event. Five examples are presented, involving infants aged 3 to 10 months, and ranging over several facets of infants' physical reasoning. It is argued in each case that infants' failure to look preferentially at the impossible event stems from their having arrived at some explanation for the event. In some instances, infants' explanations appear to be entirely self-produced, as when infants spontaneously posit hidden objects to make sense of otherwise impossible events. In other examples, infants' explanations appear to depend on additional clues provided, either deliberately or inadvertently, by the experimental situation. Despite these superficial differences, however, the examples are all related in suggesting that infants, like older children and adults, actively seek explanations for inconsistencies in their world.

In recent years, investigators have given increasing attention to the study of infants' understanding of the physical world (see Baillargeon, 1993, in press *a*, *b*; Spelke, 1988, 1991; Spelke, Breinlinger, Macomber & Jacobson, 1992, for recent reviews). One of the paradigms frequently used by researchers to uncover the nature of infants' expectations about objects is the violation-of-expectation paradigm. In a typical experiment, infants see two test events: a possible and an impossible event. The possible event is consistent with the expectation examined in the experiment; the impossible event, in contrast, violates this expectation. The reasoning is that if infants possess the expectation being tested, they will be surprised by the impossible but not the possible event. Because infants' surprise at an event typically manifests itself by prolonged attention to the event, it is assumed that, if infants are surprised by the impossible event, they will look reliably longer at it than at the possible event.

With the help of this methodology, investigators have been able to demonstrate considerable physical knowledge on the part of young infants. For example, we now know that young infants understand that objects continue to exist when out of sight (e.g.

* Requests for reprints.

Baillargeon, 1986, 1987*a,b,* 1991; Baillargeon & DeVos, 1991; Baillargeon & Graber, 1987; Baillargeon, Graber, DeVos & Black, 1990; Baillargeon, Spelke & Wasserman, 1985; Spelke & Kestenbaum, 1986; Spelke *et al.*, 1992), that objects cannot occupy the same space as other objects (e.g. Baillargeon, 1986, 1987*a,b,* 1991; Baillargeon & DeVos, 1991; Baillargeon *et al.*, 1985, 1990; Spelke *et al.*, 1992), that objects move along spatially continuous paths (e.g. Baillargeon, 1986; Baillargeon & DeVos, 1991; Baillargeon & Graber, 1987; Spelke *et al.*, 1992), and that objects cannot remain stable without support (e.g. Baillargeon & Hanko-Summers, 1990; Baillargeon, Needham & DeVos (1992); Needham & Baillargeon, 1993, 1994; Spelke, Jacobson, Keller & Sebba, 1993; Spelke, Simmons, Breinlinger, Jacobson & Macomber, 1993). To illustrate the violation-of-expectation paradigm, I will describe an experiment that provided evidence for the first two of these claims, that is, evidence that young infants appreciate both the permanence and the impenetrability of objects.

In this experiment (Baillargeon *et al.*, 1990), 5.5-month-old infants were shown the possible and the impossible events depicted in the upper panel of Fig. 1. At the start of the possible event, the infants saw two covers placed side by side: on the left was a clear plastic cover and on the right was a cage; a toy bear was visible inside the cage. After a few seconds, a screen was raised to hide the two covers from view. Next, a gloved hand reached behind the screen's right edge twice in succession; on the first reach, the hand reappeared with the cage, and on the second reach, with the bear. The impossible event was identical to the possible event except that the bear was under the clear cover at the start of the event and thus should still have been inaccessible to the hand after the cage was removed.

A second group of 5.5-month-old infants was tested in a control condition (see Fig. 1, lower panel) that was identical to the experimental condition except that the clear cover was replaced by a clear, shallow container. The bear's head and upper body protruded above the container's rim. In this condition, the bear was always accessible to the hand after the cage was removed.

The infants in the experimental condition looked reliably longer at the impossible event than at the possible event, whereas the infants in the control condition looked about equally at the two test events they were shown. Together, these results indicated that the infants (*a*) believed that the bear, the cage and the cover or container continued to exist, in their same locations, behind the screen; (*b*) understood that the hand and the bear could not move through the space occupied by the clear cover; and hence (*c*) were surprised in the impossible event to see the hand reappear from behind the screen holding the bear.

The results of this experiment thus indicated that by 5.5 months of age infants already share at least two of adults' beliefs about objects, namely, that objects continue to exist when out of sight and that objects cannot move through the space occupied by other objects.

Do infants seek explanations for impossible events?

Chandler & Lalonde (1994) presented 3- and 4-year-old children with an impossible event in which a screen appeared to rotate through the space occupied by a wooden block. The authors reported that their subjects reacted with marked surprise when

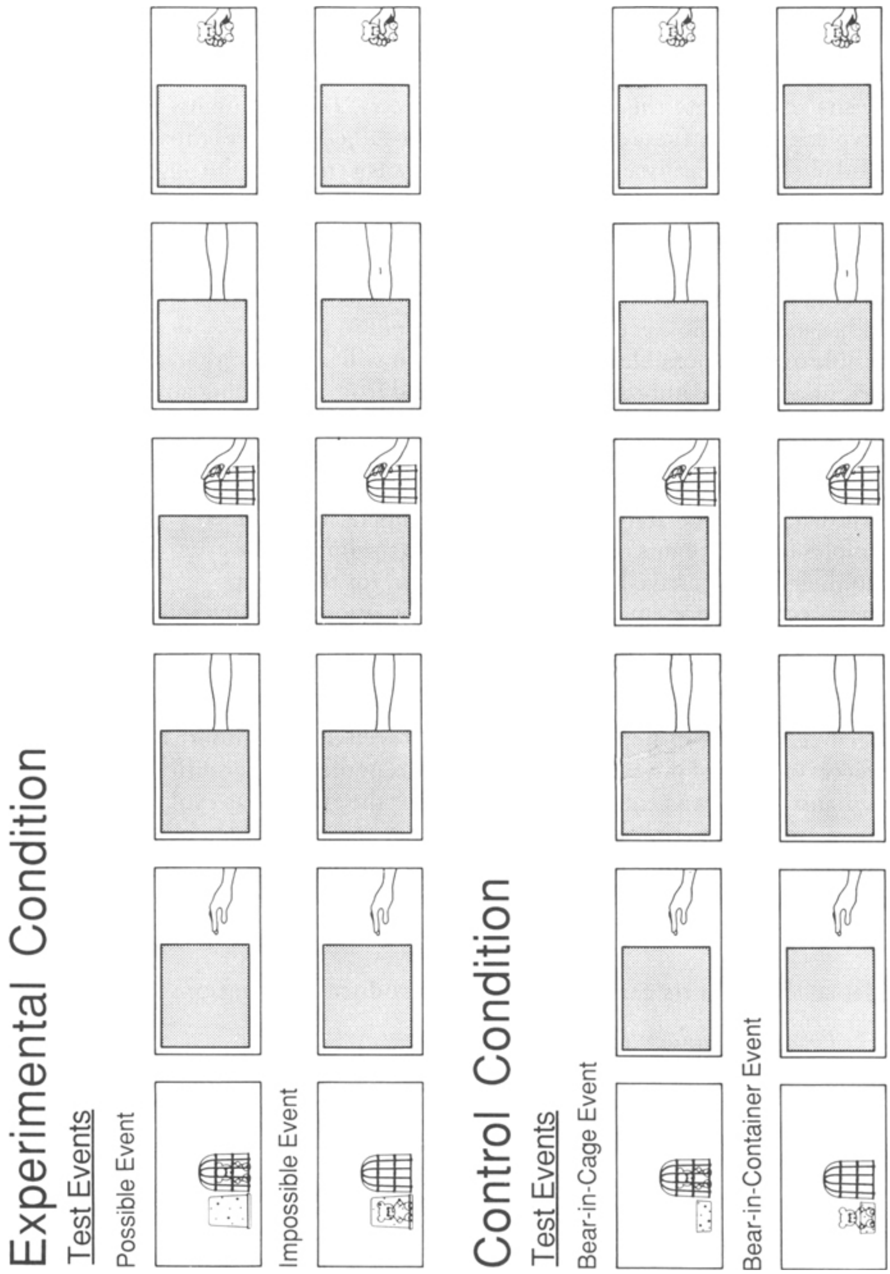

Figure 1. Schematic drawing of the test events used in Baillargeon *et al.* (1990).

shown this event, as evidenced by 'bugged eyes, beady stares, theatrical double takes, audible gasps and giggles' (p. 89). The children's responses were not limited to these surprise reactions, however; the authors indicated that virtually all of the children 'bolted from their seats to explore the apparatus', when no longer prevented from doing so, 'and eventually discovered the trap door mechanism' (p. 89).

The evidence reviewed in the previous section suggests that infants are surprised when shown events that violate their beliefs about objects. But do infants also attempt to generate explanations for these events? Unlike older subjects, such as those of Chandler & Lalonde, infants are typically unable to search for answers by exploring the apparatuses before them. Is there other evidence that could be taken to suggest that infants seek explanations for impossible events? Data from our laboratory provide intriguing hints that, like older children and adults, infants strive to reconcile what they observe with what they believe. This evidence comes from experiments in which infants were presented with an impossible and a possible event and were found *not* to show the typical preference for the impossible over the possible event. In each case it will be argued that infants' failure to look preferentially at the impossible event stemmed from their being able to generate an explanation for the event. Children and adults typically do not show surprise at events when conscious of how they were contrived; for example, it is doubtful that the subjects of Chandler & Lalonde would have been surprised to see the screen rotate through the block had they known, or immediately guessed, that the apparatus contained a trapdoor. In each of the examples below, infants' atypical response to the impossible event will similarly be ascribed to their having arrived at some explanation for the event.

In the next section, I present three examples of situations in which infants appeared to spontaneously produce explanations for events. In the following section, I discuss two examples of situations in which infants, though unable to generate explanations on their own, readily did so when provided (either deliberately or inadvertently) with additional clues. Together, the five examples involve infants aged 3 to 10 months and range over multiple facets of infants' physical reasoning. The examples further differ in that in some instances infants' ability to generate explanations for the events was explicitly anticipated in the design of the experiments, whereas in other instances this ability was entirely unexpected. Despite these differences, however, the examples are all related in suggesting that infants, like older children and adults, actively seek explanations for inconsistences in their world.

Evidence that infants can spontaneously produce explanations for events

Example 1: Positing a hidden doll

The first example comes from experiments that examined 10-month-old infants' ability to represent the existence and number of objects hidden behind a screen (Baillargeon, Miller & Constantino, 1994). The infants saw the possible and the impossible events depicted in the left panel of Fig. 2. At the start of each event, a screen was raised to hide the empty centre section of the apparatus. Next, a gloved hand entered the apparatus twice in succession, each time carrying a small 'Ernie' doll which it deposited behind the screen. The screen was then lowered to reveal a row of two dolls in the possible event, and three dolls in the impossible event (an experimenter introduced a third doll surreptitiously through a hidden door in the back wall of the apparatus). The infants in another (screen-

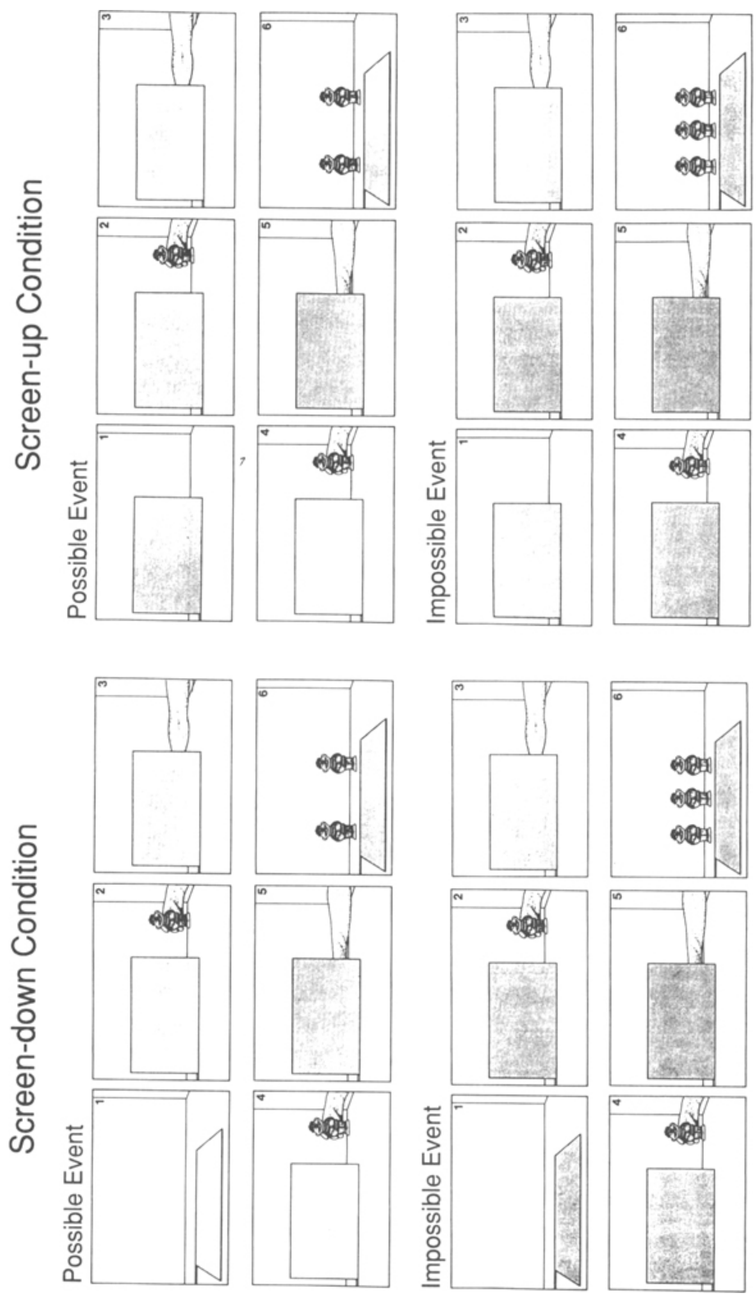

Figure 2. Schematic drawing of the test events used in Baillargeon *et al.* (1994).

up) condition saw the same test events as the infants in the first (screen-down) condition, with one exception: the events began with the screen already up, so that the infants did not see that the area behind the screen was empty (see Fig. 2, right panel).

We reasoned that if the infants in the screen-down condition (*a*) believed that each doll continued to exist after it was deposited behind the screen and (*b*) realized that the addition of one doll and then another doll behind the screen resulted in an array of two dolls, then they should be surprised in the impossible event when the screen was lowered to reveal three dolls; the infants should therefore look reliably longer at the impossible event than at the possible event. We were less certain, however, what to expect from the infants in the screen-up condition. On the one hand, their performance might be identical to that of the infants in the screen-down condition. On the other hand, it was conceivable that the infants in the screen-up condition might conclude, upon seeing the array of three dolls, that one of the dolls must have already been present behind the screen at the start of the event (though incorrect, this explanation was nevertheless plausible, given the nature of the events). In the latter case, the infants should look equally at the impossible and the possible events, because neither event would seem surprising.

The infants in the screen-down condition looked reliably longer at the impossible than at the possible event, whereas the infants in the screen-up condition tended to look equally at the two events. These results indicated that the infants in the screen-down condition (*a*) understood that depositing one doll and then another doll behind the screen should produce a set of two dolls and hence (*b*) were surprised in the impossible event when the screen was lowered to reveal three dolls. Furthermore, although the infants in the screen-up condition also appreciated that placing one and then another doll behind the screen should have resulted in an array of two dolls, these infants (*a*) concluded that one additional doll must have been present behind the screen at the start of the impossible event and hence (*b*) showed little surprise at this event.

To reiterate, what is being argued is that, upon seeing the impossible event, the infants in the screen-up condition readily constructed an explanation for this event: they assumed that one doll already stood behind the screen at the start of the event. Only the infants in the screen-down condition, who possessed information *contradicting* this explanation and thus were unlikely to generate it, showed reliable surprise at the impossible event.

The findings of this experiment (which were replicated in additional experiments: Baillargeon *et al.*, 1994) provide evidence that infants, like adults, attempt to reconcile what they observe with what they believe. By assuming that a doll already stood behind the screen at the start of the event, the infants in the screen-up condition were able to transform an event that would otherwise have violated their beliefs about objects into an event entirely consistent with their beliefs.

Example 2: Positing a hidden rabbit

The second example to be described in this section involves experiments that examined 5.5-month-old infants' ability to represent the existence, height and trajectory of hidden objects (Baillargeon & Graber, 1987). In one experiment, the infants were familiarized with a toy rabbit that slid back and forth along a horizontal track whose centre was occluded by a screen; the rabbit disappeared at one edge of the screen and reappeared, after an appropriate interval, at other edge (see Fig. 3). On alternate trials, the infants saw a short or a tall rabbit slide along the track. Following familiarization, the midsection of the screen's upper half was removed, creating a large window. The infants then saw a possible and an impossible test event. In the possible event, the short rabbit moved back and forth along the track; this rabbit was shorter than the window's lower edge and so did not appear in the window when passing behind the screen. In the impossible event, the tall rabbit moved along the track; this rabbit was taller than the window's lower edge and hence should have appeared in the window but did not in fact do so. To produce this event, as well as the other test and familiarization events, two identical rabbits were used: one rabbit moved from the left end of the track to the left edge of the screen and stopped just inside this edge; another, identical rabbit then emerged from the right edge of the screen and travelled to the right end of the track.

The infants tended to look equally at the short- and the tall-rabbit familiarization events but looked reliably longer at the impossible test event than at the possible test event. These results indicated that the infants (*a*) believed that each rabbit continued to exist behind the screen; (*b*) realized that each rabbit retained its height behind the screen; (*c*) assumed that each rabbit pursued its trajectory behind the screen; and hence (*d*) expected the tall rabbit to appear in the screen window and were surprised that it did not.

The results of the experiment also indicated that the infants were impervious to the auditory clues that signaled how the familiarization and test events were produced. Whereas a distinct metallic noise could be heard during the visible portions of the tall or the short rabbit's trajectory, on either side of the screen, no noise was heard after each rabbit disappeared behind the screen. To naïve adults who watched the events, the absence of noise during the occluded portion of each rabbit's trajectory provided a powerful hint that two separate rabbits were involved in the events, one travelling to the left and the other to the right of the screen. The fact that the 5.5-month-old infants in the experiment appeared unaware of these auditory clues was not unexpected, however, given prior reports that young infants do not make use of available sound clues to track or locate occluded objects (e.g. Meicler & Gratch, 1980; Nelson, 1971; Piaget, 1954).

Although the infants in the experiment were unable to infer that two distinct rabbits were used to produce the impossible event, the results of another, unpublished experiment suggest that, under some conditions, 5.5-month-old infants *can* spontaneously generate such an explanation. The infants in this experiment (see Fig. 4) saw the short-rabbit familiarization event used in the first experiment. Next, the infants watched a possible and an impossible test event. The possible event was the same as that shown to the infants in the first experiment. The impossible event was identical to the possible event with one exception: the window was at the bottom rather than at the top of the screen. In this event, the short rabbit should have appeared in the window when passing behind the screen; it did not, however, do so. As before, two identical rabbits were used to produce the familiarization and test events.[1]

[1] For details of apparatus, events and procedure, the reader is referred to Baillargeon & Graber (1987, Expt 1). Subjects in the experiment were 12 infants ranging in age from 4 months 29 days to 6 months 1 day (M = 5 months 10 days). Three additional infants were eliminated, two because of fussiness and one because of drowsiness. The infants saw the short-rabbit familiarization event on four successive trials; they then watched the possible and the impossible test event on alternate trials until they had completed four pairs of test trials (order of presentation of the two test events was counterbalanced across subjects). Three infants completed only six test trials because of fussiness, but were still included in the data analyses.

Given the results of the tall/short-rabbit experiment, it is likely that the infants in the upper/lower-window experiment perceived the short-rabbit familiarization event in terms of a single short rabbit moving back and forth along the track. How did the infants perceive the test events? It can be seen in Fig. 5 that, unlike the infants in the tall/short-rabbit experiment, the infants in the upper/lower-window experiment tended to look equally at the impossible and the possible events.[2] We were initially puzzled by this finding: how could the infants in the tall/short-rabbit experiment be surprised that the upper portion (7.5 cm) of the tall rabbit failed to appear in the screen window, and the infants in the upper/lower-window experiment *not* be surprised that the whole of the short rabbit (15.5 cm) failed to appear in the window? Upon reflection, we came to the hypothesis that, like the 10-month-old infants discussed earlier, the 5.5-month-old infants in the second experiment did not show surprise at the impossible event because they were able to generate an explanation for this event. Specifically, they realized that the short rabbit did not appear in the screen window because it did not in fact travel the distance behind the screen; instead, two identical short rabbits were involved in the production of the event, one travelling to the left and the other to the right of the screen.

It might be objected that other, less interesting hypotheses could be advanced for the results of the upper/lower-window experiment. For example, it could be argued that, because the infants saw the short rabbit in each familiarization and test trial, rather than the short and the tall rabbit on alternate trials, they were generally less engaged by the events and hence less likely to detect the surprising character of the impossible event. However, statistical analyses revealed no significant differences between the overall looking times of the infants in the tall/short-rabbit and the upper/lower-window experiments during the test trials.[3]

The results of the upper/lower-window experiment (which were replicated in another experiment[4]) suggest two conclusions. First, the results provide further evidence that infants, like older children and adults, attempt to reconcile what they observe with what

[2] The infants' looking times in the tall/short-rabbit experiment (Baillargeon & Graber, 1987, Expt 1, medium/short condition) and the upper/lower-window experiment were analysed by means of a 2 × 4 × 2 mixed-model analysis of variance with experiment (tall/short-rabbit or upper/lower-window) as a between-subjects factor and with test pair (first, second, third or fourth) and event (impossible or possible) as within-subjects factors. The analysis yielded a significant experiment × event interaction ($F(1,81) = 4.55$, $p < .05$). Planned comparisons revealed that, whereas the infants in the tall/short-rabbit experiment looked reliably longer at the impossible ($M = 34.4$) than at the possible ($M = 27.8$) event ($F(1,81) = 5.20$, $p < .05$), the infants in the upper/lower-window experiment tended to look equally at the two events ($F(1,81) = 0.22$) (impossible: $M = 27.7$; possible: $M = 29.0$).

[3] The main effect of experiment was not statistically significant ($F(1,22) = 0.80$), suggesting that there were no reliable differences between the overall looking times of the infants in the tall/short-rabbit ($M = 31.1$) and the upper/lower-window ($M = 28.4$) experiments during the four test pairs.

[4] Subjects in this replication were 12 infants ranging in age from 5 months 3 days to 5 months 28 days ($M = 5$ months 16 days). Half of the infants saw the same familiarization and test events as the infants in the initial upper/lower-window experiment. The other half of the infants saw the same events except that short rabbits of different colours were used on alternate trials (the rabbits were either pink and green, as in Baillargeon & Graber, 1987, Expt 1, or blue and yellow, as in Baillargeon & Graber, 1987, Expt 2); this colour change had no discernible effect on the infants' responses. Four of the 12 infants in the experiment failed to complete all four pairs of test trials because of fussiness; three infants completed only three pairs and one infant completed only two pairs. All of the infants were included in the data analyses. The infants' looking times at the impossible and the possible events were analysed by means of a 4 × 2 mixed-model analysis of variance with test pair (first, second, third or fourth) and event (impossible or possible) as the within-subject factors. The main effect of event was not significant ($F(1,39) = 0.60$), indicating that the infants tended to look equally at the impossible ($M = 30.9$) and at the possible ($M = 28.3$) event.

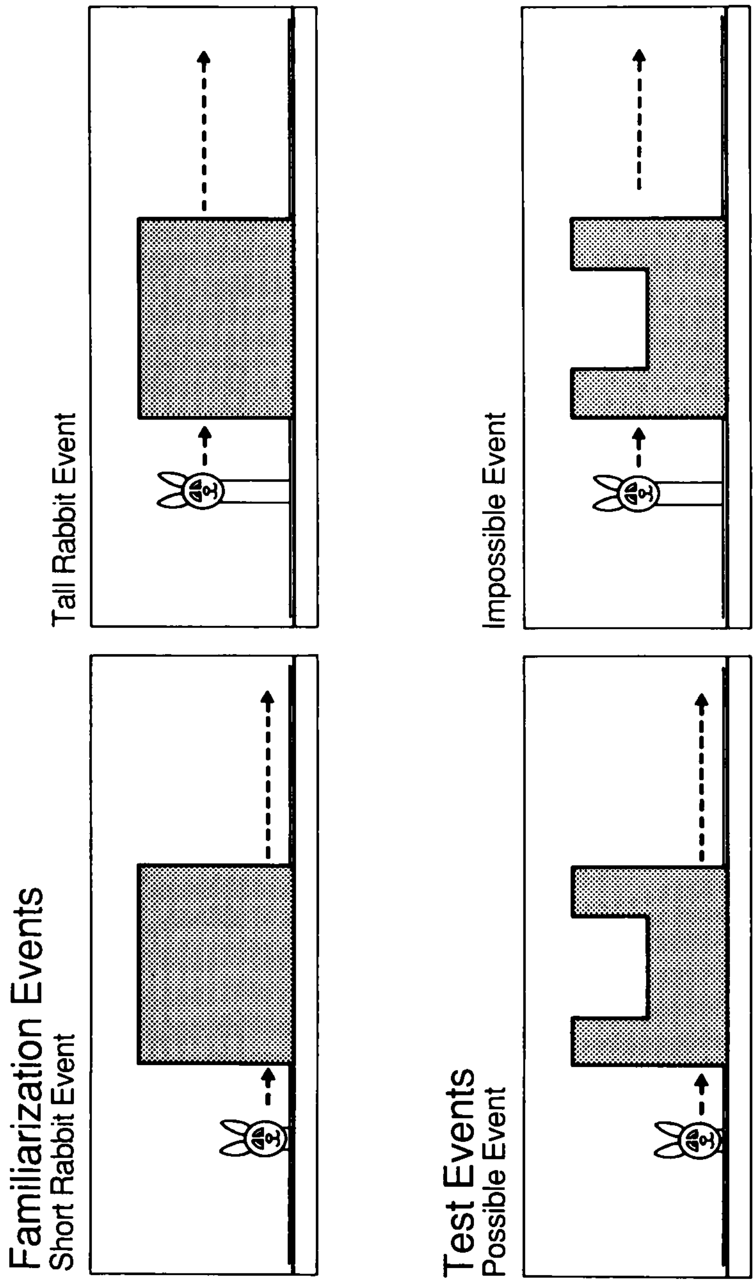

Figure 3. Schematic drawing of the test events used in Baillargeon & Graber (1987, Expt 1).

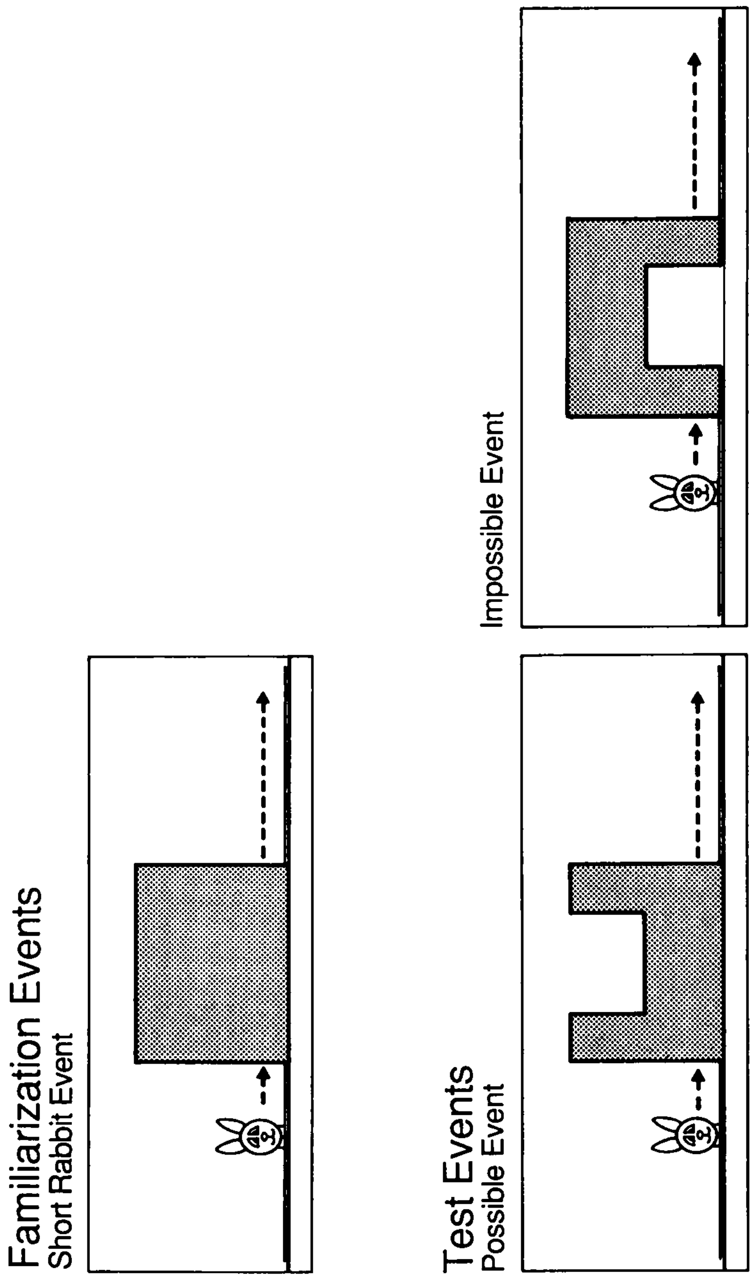

Figure 4. Schematic drawing of the test events described in the text.

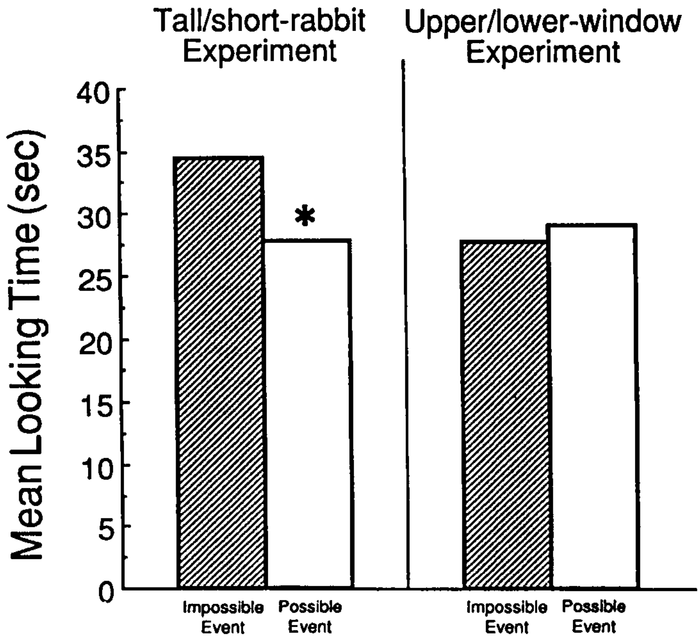

Figure 5. Mean looking times of the infants in the tall/short-rabbit and the upper/lower-window experiments at the impossible and the possible events.

they believe. By assuming that two different rabbits were involved in the impossible event, the infants were able to transform an event that would otherwise have contradicted their beliefs about objects into an event entirely consistent with these beliefs.[5]

Second, the discrepancy between the results of the upper/lower-window and the tall/short-rabbit experiments suggests that infants' success at generating an explanation for a given impossible event does not ensure that they will be able to do the same when shown another, even highly similar impossible event. Why did the infants in the tall/short-rabbit experiment fail to posit the existence of a second tall rabbit? Is it that these infants were led by the experimental context to perceive that the tall rabbit in the impossible event was behaving as though it were *shorter* while behind the screen, and so were led to puzzle over inexplicable deformations or shrinkages, rather than to guess at the existence of a second, identical rabbit? Could the infants have been given additional clues that

[5] Experiments are planned to gather additional evidence for the conclusion that the infants in the upper/lower-window experiment readily inferred, upon seeing the impossible event, that two short rabbits were used to produce the event. In one experiment, for example, the infants will see the same familiarization and test events as the infants in the upper/lower-window experiment, except that the screen will lay flat against the floor of the apparatus, towards the infants, at the start of each trial; only one short rabbit will be visible, in the starting position at the left end of the track. After a few seconds, the screen will be raised, and the events will proceed as before. The infants in this experiment will thus be given information contradicting the hypothesis that two rabbits were used to produce the impossible event. We expect that, because the infants will lack a tenable explanation for the impossible event, they will now show reliable surprise at this event.

would have led them to respond like the infants in the upper/lower-window experiment? I return to this question in the next section of the paper.

Example 3: Positing support for a box

The last example in this section involves experiments on infants' intuitions about support relations between objects. In one experiment (Baillargeon *et al.*, 1992), 6.5-month-old infants watched the possible and the impossible events depicted in Fig. 6 (left panel). In both events, the infants saw the extended index finger of a gloved hand push a box from left to right along the top of a platform. In the possible event, the box was pushed until only its leading edge reached the end of the platform. In the impossible event, the box was pushed until only its left corner remained on the platform; the box was then inadequately supported and should have fallen but did not in fact do so (it was secured, out of sight, to the back of the apparatus). A second group of 6.5-month-old infants was tested in a control condition that was identical to the experimental condition except that the hand grasped the box throughout the events, so that the box was always adequately supported (see Fig. 6, right panel).

The infants in the experimental condition looked reliably longer at the impossible than at the possible event, whereas the infants in the control condition tended to look equally at the two test events. These results indicated that the infants (*a*) believed that the box could not remain stable without adequate support; (*b*) realized that the box was inadequately supported when only its left corner remained on the platform; and hence (*c*) expected the box to fall in the impossible event and were surprised that it did not.

The results of this first experiment indicated that by 6.5 months of age infants expect a box to fall when it loses sufficient contact with a supporting platform. Our next experiment asked whether younger infants, 3.5-month-old infants, expect a box to fall when it loses *all* contact with a supporting platform (Needham & Baillargeon, 1994). This experiment was similar to the last experiment with two exceptions. First, in the impossible event, the box was pushed until it was completely off the platform and stood suspended in mid-air (see Fig. 7, left panel). Second, prior to seeing the test events, the infants received an orientation trial designed to highlight the relation between the hand and the box. During this trial, the infants in the experimental condition saw the hand's extended index finger alternately in contact with the box or pointing at the box from a distance of 10 cm. Similarly, the infants in the control condition saw the hand alternately grasping the box or holding the same position 10 cm from the box (see Fig. 7, right panel).

The initial analysis of the results indicated that the infants in the experimental and the control conditions tended to look equally at the test events they were shown. However, closer examination of the data suggested that this pattern of results represented the average of two distinct looking patterns, one displayed by the younger (range 3 months 0 day to 3 months 10 days; $M = 3$ months 6 days) and the other by the older (range 3 months 11 days to 3 months 21 days; $M = 3$ months 15 days) infants in the experiment. Let us first consider the results obtained with the younger infants. The infants in the experimental condition looked reliably longer at the impossible than at the possible

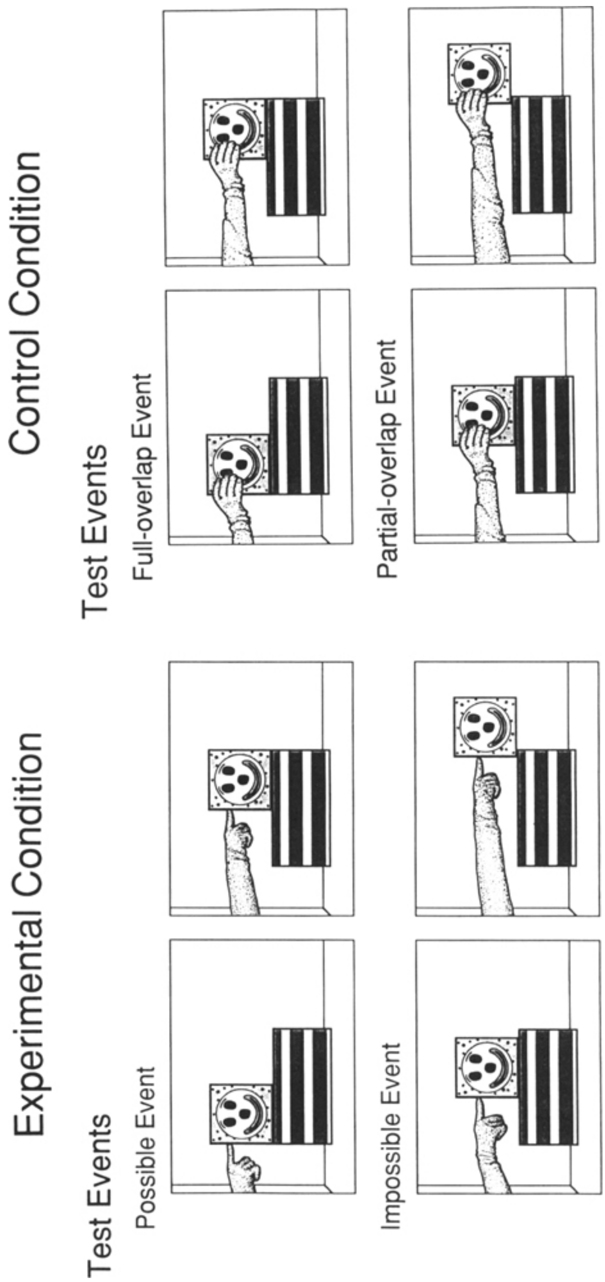

Figure 6. Schematic drawing of the test events used in Baillargeon *et al.* (1992).

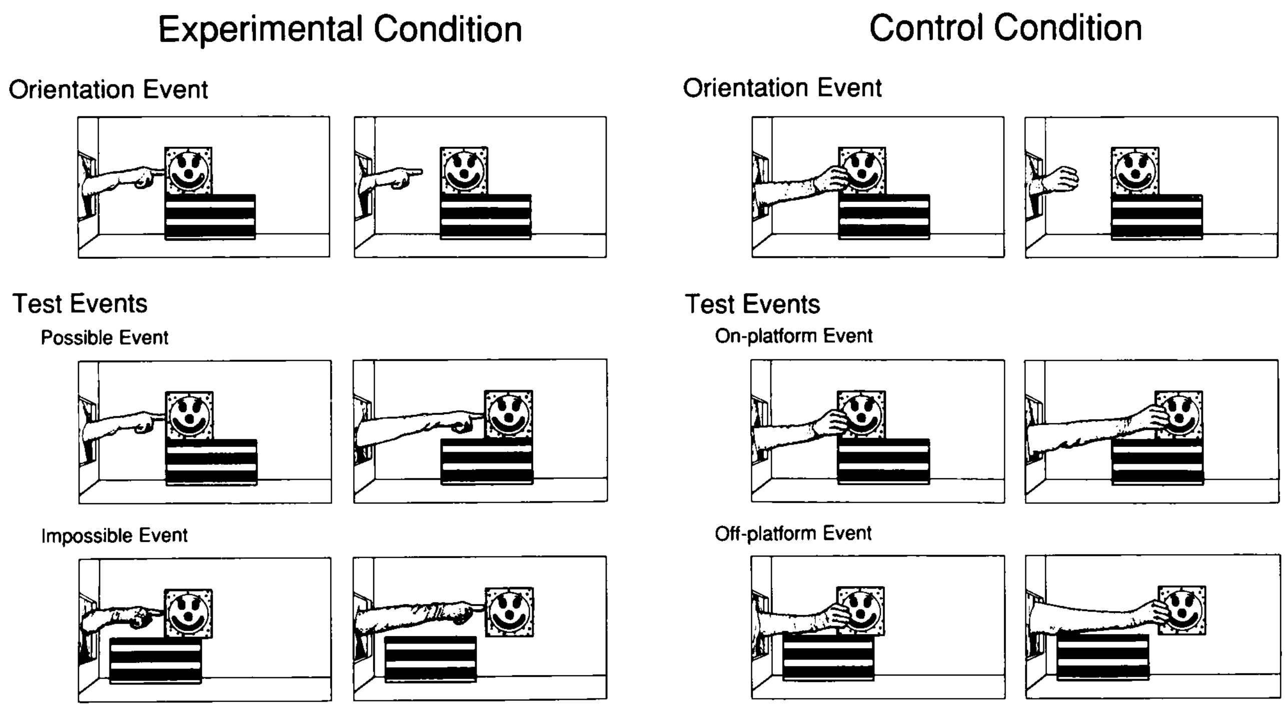

Figure 7. Schematic drawing of the orientation and test events used in Needham & Baillargeon (1994, Expt 1).

event, whereas the infants in the control condition looked about equally at the two test events. Together, these results suggested that the infants (*a*) believed that the box could not remain stable without support and hence (*b*) expected the box to fall when it was pushed off the platform and were surprised that it did not.

Let us now turn to the results obtained with the 3.5-month-old infants. Unlike the younger infants, these infants tended to look equally at the impossible and the possible events. One interpretation of this negative finding was that, like the 10- and 5.5-month-old infants in the preceding examples, these 3.5-month-old infants were generating an explanation for the violation shown in the impossible event. The question was: what explanation were the infants producing? There were multiple clues in the experimental situation that the box had a hidden means of support. The box was mounted on a metallic rod that slid along a metallic track; the movements of the box were thus correlated with a soft but noticeable metallic noise. In addition, the box moved along a perfectly regular, straight path that was somewhat inconsistent with its being merely pushed by a finger (that is, some deviations might have been expected across repetitions). However, it seemed highly improbable that the infants were using these clues since the 6.5-month-old infants in the first support experiment were clearly impervious to them (recall that they showed a reliable preference for the impossible over the possible event).

It then occurred to us that perhaps the 3.5-month-old infants in the second experiment were assuming that (*a*) because the hand's index finger was the only object in contact with the box when it was suspended in mid-air, the finger must be supporting the box; and (*b*) because the finger could not ensure the box's support merely by touching it (a fact that even the 3-month-old infants seemed to understand), the finger must now be *attached* to the box.

Further analyses provided evidence for this hypothesis. Although the 3.5-month-old infants in the experimental condition tended to look equally at the impossible and possible events, their mean looking time at these events ($M = 42.3$) was found to be reliably greater than their mean looking time at the control test events ($M = 31.9$), and to be statistically equal to the mean looking time of the 3-month-old infants in the experimental condition at the impossible event ($M = 44.8$). These data suggested that the 3.5-month-old infants in the experimental condition (*a*) believed that the box could not remain stable without support; (*b*) concluded that the box must now be attached to the finger; (*c*) were puzzled by this state of affairs since the box and the finger had clearly been separate during the orientation trial given prior to the test trials; and hence (*d*) perceived *both* the impossible and the possible events (in which the box and the finger were now mysteriously attached) as surprising.

Did the 3.5-month-old infants in the experimental condition believe that the box remained stable when pushed off the platform because it was now attached to the hand's finger? To answer this question, we tested an additional group of 3.5-month-old infants in a condition identical to the experimental condition, with one exception. In each test event, after pushing the box to the end of its trajectory, the hand bent its index finger so that it was no longer in contact with the box (see Fig. 8). The infants in this condition were thus given information in the test events contradicting the hypothesis that the finger was attached to the box.

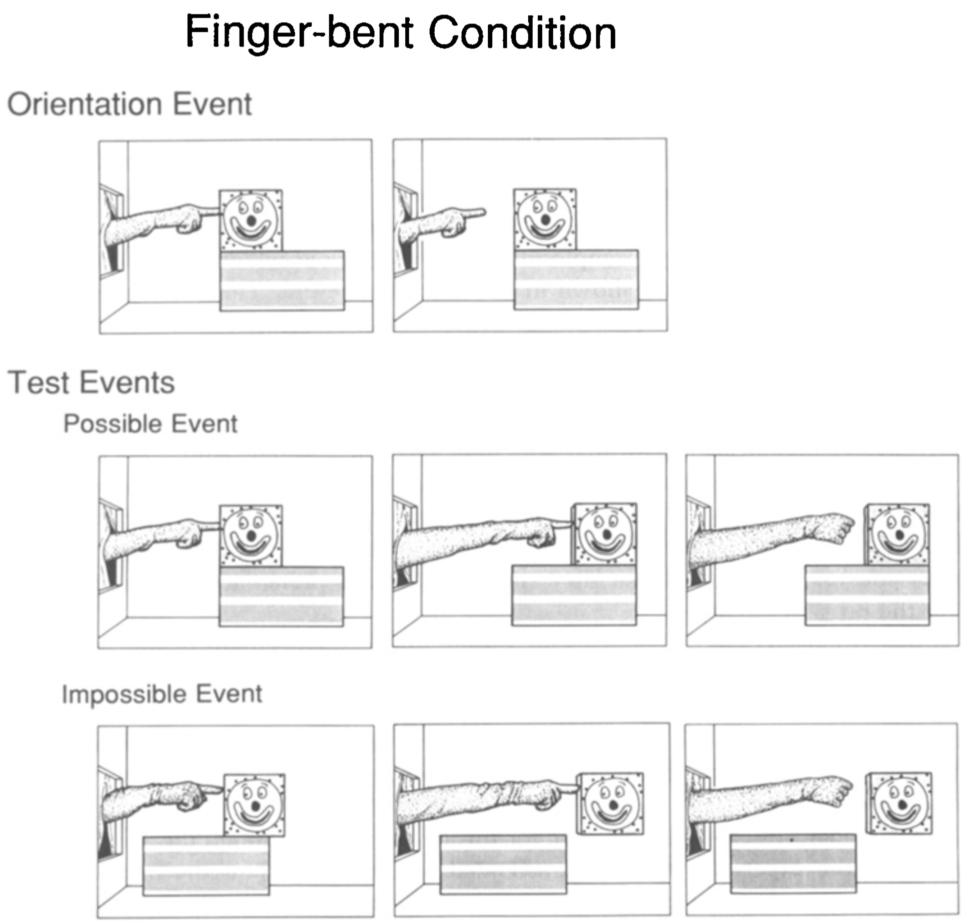

Figure 8. Schematic drawing of the orientation and test events used in Needham & Baillargeon (1994, Expt 2).

The infants in this condition looked reliably longer at the impossible than at the possible event. This finding provided support for the hypothesis that the 3.5-month-old infants in the experimental condition believed that the box did not fall when pushed off the platform because it was attached to the hand's finger. When this explanation was no longer tenable—because the box remained suspended in mid-air even after the hand bent its finger and thus broke contact with the box—the infants showed the expected preference for the impossible over the possible event.

The results discussed in this example suggest two conclusions. First, they provide further evidence that infants, like older children and adults, seek explanations for events that violate their beliefs about objects. By assuming that the finger had become attached to the box, the 3.5-month-old infants in the experimental condition could make sense of the fact that the box did not fall when pushed off the platform. True, the infants then had to wonder how the finger and the box, seen to be separate in the orientation trial, could have become attached during the test trials. Nevertheless, the very fact that infants as young as 3.5 months of age should attempt to explain events suggests that, from a very early age, infants strive to preserve their beliefs about the world.

Second, the present results point to developmental differences in infants' explanations for events. The 3-, 3.5- and 6.5-month-old infants in the experiments discussed in this example responded very differently to the events they were shown. Further research is needed to shed light on the various factors (e.g. physical knowledge, problem-solving ability) that affect (*a*) whether infants are able to generate explanations for events; (*b*) what the content of these explanations is likely to be; and (*c*) how these answers change with age.

Evidence that infants can make use of clues to generate explanations for events

In the preceding section I presented three examples of situations in which infants appeared to spontaneously generate explanations for events. In this section, I discuss two examples of situations in which infants were found to take advantage of clues provided by the experimental situation (deliberately in the first example, inadvertently in the second) to make sense of events.

Example 1: A tale of two rabbits

Recall that in the tall/short-rabbit experiment described in the previous section (Baillargeon & Graber, 1987), the infants showed reliable surprise when the tall rabbit failed to appear in the screen window, despite the fact that auditory clues pointed to how this impossible event was produced. In a further experiment, we sought to establish whether 5.5-month-old infants could take advantage of a very different hint to recognize how the impossible event was contrived. In this experiment (Baillargeon & Graber, 1987, Expt 2), 5.5-month-old infants were assigned to one of two conditions. The infants in the standard condition were tested with a procedure similar to that in the first experiment; the infants in the pretest condition saw the same familiarization and test events as the infants in the standard condition, with one exception: prior to the familiarization events, the infants received two pretest trials in which they saw *two* short or *two* tall rabbits standing motionless on either side of the windowless familiarization screen (see Fig. 9). The infants saw the two short rabbits in one trial and the two tall rabbits in the other trial, with order of presentation counterbalanced.

As expected, the infants in the standard condition looked reliably longer at the impossible than at the possible event; in contrast, the infants in the pretest condition tended to look equally at the two events. These results suggest that the infants in the pretest condition made use of the information presented in the pretest trials and understood that the tall rabbit did not appear in the screen window in the impossible event because it did not travel the distance behind the screen; instead, two identical rabbits travelled along the track, one to the left and the other to the right of the screen.

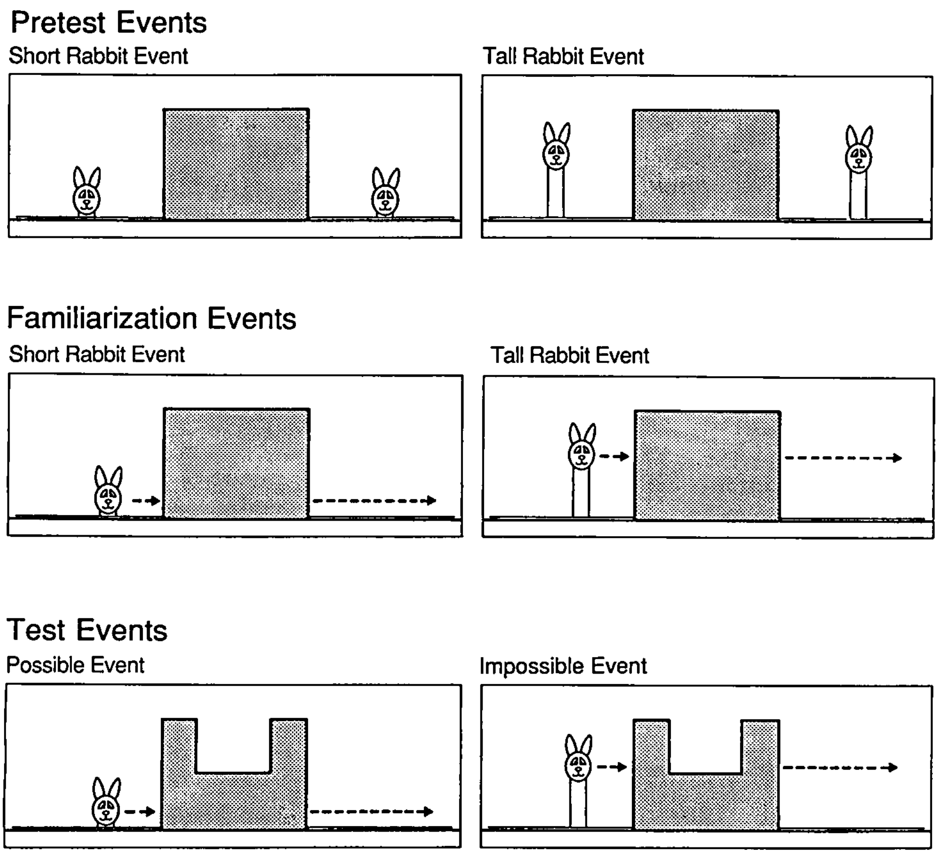

Figure 9. Schematic drawing of the test events used in Baillargeon & Graber (1987, Expt 2).

These results provide suggestive evidence that infants can take advantage of available hints to make sense of events that would otherwise have appeared surprising. In future experiments, it may be worth investigating the effect of providing such hints later in the experimental session. In the present experiment, the hint was given at the very start of the experiment, which renders the results open to two interpretations. On the one hand, the infants could have viewed all of the familiarization and test events as involving two identical rabbits and thus never viewed the impossible event as surprising or as requiring explanation. On the other hand, the infants could have perceived each of the familiarization events as involving one rabbit and only when shown the impossible event (*a*) recalled having seen the two tall rabbits and (*b*) made use of this information to generate an explanation for the event. These two interpretations differ in one important respect: whereas the second provides evidence of infants' eagerness to reconcile what they observe with what they believe, the first merely points to infants' sensitivity to contextual clues in interpreting events.

If infants were given a hint about the production of an impossible event not at the start of the experiment but, for example, after the second pair of test trials, one could establish, with proper controls, that (*a*) the infants were initially surprised (e.g. on the first two test pairs) by the impossible event but (*b*) this surprise response disappeared (e.g. on the last two test pairs) after the infants were provided with an appropriate hint.

An experiment by Spelke & Kestenbaum (1986) could be taken to suggest that hints to infants about impossible events may be effective even *retrospectively*. In this experiment, 4-month-old infants were habituated to a cylinder that slid from left to right along a track. The midsection of the track was partly hidden by two screens separated by a gap. The cylinder disappeared behind the left edge of the left screen and reappeared some time later from behind the right edge of the right screen, without having appeared between the two screens. The infants were thus habituated to an impossible event. Following habituation, the screens were removed, and the infants saw two test events. In one, two cylinders travelled along the track; one cylinder had the same trajectory as the cylinder seen to the left of the screen in the habituation event, and the other cylinder had the same trajectory as the cylinder seen to the right of the screen in the habituation event. In the other test event, a single cylinder moved along the track, following either one of the trajectories (left or right) seen in the first test event. The results indicated that the infants looked reliably longer at the second than at the first test event. The authors took these results to mean that the infants (*a*) assumed, upon seeing the habituation event, that two distinct cylinders were used to produce the event, one travelling to the left and the other to the right of the two screens, and hence (*b*) were surprised when the screens were removed to see a single cylinder travelling along the track. However, the data are also open to another interpretation: it could be that the infants were puzzled by the habituation event, and only recognized that two cylinders were used to create it when shown the two-cylinder test event. If the explanation offered by Spelke & Kestenbaum is correct, it would suggest that infants as young as 4 months of age are able to spontaneously posit hidden objects to make sense of events that would otherwise be in violation of their beliefs about the world. If the alternative interpetation just proposed is correct, it would suggest that hints given even *after* infants are exposed to impossible events can be used to generate explanations for the events.[6]

The results presented in this example suggest that it may be possible to design experiments in which infants are found to use hints to make sense of events they initially view as surprising. Like the evidence discussed in the previous section, such evidence would be useful in demonstrating that infants, like older children and adults, actively seek explanations for events that violate their beliefs about objects: even when unable to generate such explanations on their own, infants would readily take advantage of available hints to do so.

[6] Spelke & Kestenbaum (1986) included in their figures habituation data from (*a*) infants who saw an event in which the cylinder did not appear between the screens and (*b*) infants who saw an event in which the cylinder did appear between the two screens. Visual examination of the data suggests that the two groups were comparable, supporting their interpretation of the test data. Caution is needed in interpreting these habituation results, however, because only the data from the last six trials are included in the figures. If the infants typically received many more trials (the average number is not reported), whatever surprise the infants experienced at the cylinder's failure to appear between the screens could be difficult to discern after several trials (even adults become blasé after seeing 30 rabbits pulled out of a hat).

Example 2: A case of noisy magic

Recall that in the first support experiment described in the previous section, 6.5-month-old infants were surprised that the box did not fall when only its left corner remained on the platform (Baillargeon *et al.*, 1992). For reasons that are not relevant here, we also tested 9.5-month-old infants with the same procedure (Baillargeon & Raschke, in preparation). To our surprise, these older infants, unlike the 6.5-month-old infants, showed no preference for the impossible over the possible event.

Our first interpetation for this negative finding was that our procedure was not suitable for the testing of older infants. We then began a long series of pilot experiments in which we modified various aspects of our procedure (e.g. we shortened the maximum length of each trial from 60 s to 30 s) in an attempt to render it more age-appropriate. None of these modifications proved helpful. The 9.5-month-old infants consistently failed to show surprise at our impossible event.

It then occurred to us that perhaps these older infants were not surprised at our impossible event because they were able to infer how it was produced. Recall that there were multiple clues that the box had a hidden means of support: a metallic noise originating behind the box could be heard whenever it moved, the box followed an improbable, perfectly straight path on every trial, and so on. Although the 6.5-month-old infants in our experiment appeared impervious to these clues (since they showed a reliable preference for the impossible event), it was possible that the 9.5-month-old infants were not. Some data were consistent with this notion. There is evidence in the literature that 9-month-old infants can use subtle auditory clues to guide their search for hidden objects (e.g. Rieser, Doxsey, McCarrell & Brooks, 1982). Furthermore, there are data indicating that 9.5-month-old infants can use visual clues (such as the presence of a protuberance in a soft cloth cover) to infer the presence of a hidden object (Baillargeon & DeVos, 1994). Therefore, it seemed possible that the infants were using some of the clues available in the situation to infer that a hidden mechanism supported the box.

This interpretation placed us in the unenviable position of inept magicians who fail to draw gasps of surprise from their audience because their tricks are too readily understood. We therefore set about improving our magic, so to speak, and eventually settled on the experimental procedure illustrated in Fig. 10 (upper panel). Although our data collection is not entirely complete, the results obtained so far are extremely promising. In the possible event, the infants see one box standing on another box, with the edges of the two boxes aligned. In the impossible event, only the right corner of the top box is in contact with the lower box. Note that there is no movement at all in these events; the boxes are in the positions indicated at the start of each trial and remain in the same positions until the trial ends. The infants in the control condition see events that are identical except that the hand grasps the top box, instead of simply pointing at it (see Fig. 10, lower panel).

Analysis of the available data yielded a significant condition × event interaction. The infants in the experimental condition looked longer at the impossible than at the possible event, whereas the infants in the control condition tended to look equally at the test events. These results suggest that, like the 6.5-month-old infants we first tested, the infants (*a*) realize that the box is inadequately supported when only its corner is

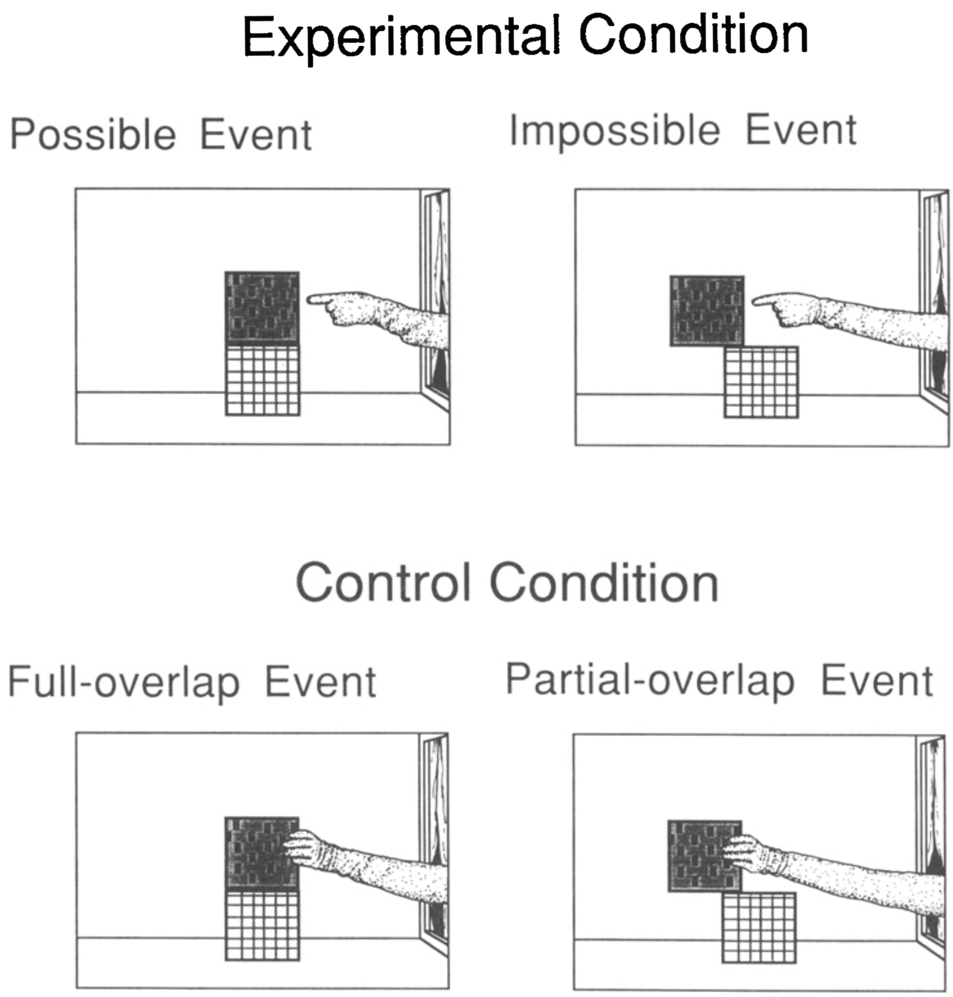

Figure 10. Schematic drawing of the test events used in Baillargeon & Raschke (in preparation).

supported and hence (*b*) expect the box to fall in the impossible event and are surprised that it does not.

These results give weight to the hypothesis that the 9.5-month-old infants in our initial experiment failed to prefer the impossible event because they were able to use the clues present in the experimental situation to infer an explanation for the event. Only when faced with an impossible event from which most clues had been removed did the infants show reliable surprise at the event.

To bolster the above conclusion, additional experiments are needed to determine exactly which clues the 9.5-month-old infants in the initial experiment (and the subsequent pilot experiments) used to produce an explanation for the impossible event.

More generally, it would be interesting to uncover the range of clues infants can use, at different ages, to infer that an object has a hidden means of support. The evidence discussed in this example already points to developmental differences in infants' sensitivity to such clues: recall that, unlike the 9.5-month-old infants, the 6.5-month-old infants in our initial experiment appeared impervious to the clues contained in the experimental situation. We have recently begun an experiment investigating 3- and 3.5-month-old infants' ability to use a very different clue. This experiment is identical to the experiment described above (Needham & Baillargeon, 1994) in which infants observed a finger push a box off a platform (see Fig. 7), with one exception: at the start of the experiment, the infants receive a pretest trial in which the front of the box is removed and a hand (different from the hand that pushes the box) can be seen through the opening to be holding on to the box. Like the 5.5-month-old infants in the two-rabbit experiment described in our last example, these infants are thus given a deliberate hint (in this case an incorrect though plausible hint) as to how the impossible event is contrived. The data collected so far suggest that the infants tend to look equally at the impossible and the possible events. If confirmed by appropriate controls, this finding will indicate that young infants are sensitive to at least certain types of clues when attempting to make sense of apparent support violations.

Discussion

Over the past few years, researchers have gathered considerable evidence that infants are surprised when shown events that violate their beliefs about the world, as indexed by reliably greater looking times at these events than at events consistent with their beliefs (see Baillargeon, 1993, *a,b*; Spelke, 1988, 1991; Spelke *et al.*, 1992, for recent reviews). At the same time, a few situations have emerged in which infants have been found *not* to look preferentially at events that violate, as opposed to confirm, their beliefs about objects. Several such situations were discussed in the present paper. In each case, it was argued that the infants failed to show the typical preference for the impossible event they were shown because they held some explanation for the event. In some instances, the infants were able to spontaneously generate an explanation. Recall, for example, the 10-month-old infants in the first example who assumed, upon seeing the impossible event, that an additional doll must have been present behind the screen at the start of the event. In other situations, the infants, though unable to produce an explanation spontaneously, could do so when provided with appropriate hints. To illustrate, recall the 9.5-month-old infants in the last example who were unable to infer that the box had a hidden means of support when shown static events, but had little difficulty doing so when presented with dynamic events containing additional clues.

Although much of the evidence presented in this paper is still preliminary, it already suggests several interesting directions for future research. A number have already been alluded to. First, under what conditions are infants likely to spontaneously produce explanations for impossible events? Recall that the 5.5-month-old infants in the upper/lower-window experiment were able to guess at the existence of a second rabbit behind the screen, but the infants in the tall/short-rabbit experiment could not. Second, what hints are infants able to use to arrive at explanations for events? The 5.5-month-old infants in the tall/short-rabbit experiment were unable to use the available auditory clues to make sense of the impossible event; however, they readily understood how this event was contrived after seeing the two tall, stationary rabbits. Finally, how do the answers to these questions change with development? Comparison of the performances of the 6.5- and 9.5-month-old infants in our support experiments, for example, suggests that the older but not the younger infants were sensitive to the auditory and visual clues contained in the events.

Beyond these more immediate suggestions for future research, the results reviewed in this paper also have broader implications for our conception of infants' physical reasoning. Consider the picture that is suggested by the present results—one in which infants are seen to be busily interpreting events in terms of their store of physical knowledge and, when inconsistencies arise, to be actively seeking solutions reconciling their observations with their beliefs. This picture is strikingly different from more traditional conceptions of infants' physical reasoning, in two respects. First, it grants far more physical knowledge to infants than was previously done: the infants in the present experiments clearly believed, for example, that objects continue to exist when hidden, that objects cannot occupy the same space as other objects, that objects cannot appear at two separate points in space without having travelled the distance between them, and that objects cannot remain stable without support. Second, the picture suggested by the present results assumes that infants' interpretation of physical events involves a *conceptual* analysis similar to that engaged in by older children and adults. The 10-month-old infants in the first example presented did not merely process each doll's gradual occlusion at the screen edge to signal the doll's continued existence behind the screen; the infants spontaneously *posited* the presence of a third doll behind the screen to make sense of the events they were watching. Such observations are difficult to reconcile with the notion that infants' interpretation of events is limited to the detection and processing of perceptual invariants; these observations are easily understood, however, in a model that views infants, like older children and adults, as engaging in a knowledge-based, conceptual analysis of the physical world.

Acknowledgements

The research reported in this paper was supported by a grant from the National Institute of Child Health and Human Development (HD-21104). Portions of this paper were presented at the Biennial Meeting of the International Society for the Study of Behavior and Development, Minneapolis, July 1991. I thank Jerry DeJong, Judy DeLoache and Paul Harris for insightful comments; Elizabeth Mazenko for her help with the data analyses; and Lincoln Craton, Julie DeVos, Myra Gillespie, Marcia Graber, Valerie Kolstad, Laura Kotovsky, Amy Needham and the undergraduate students working in the Infant Cognition Laboratory at the University of Illinois for their help with the data collection. I also thank the parents who kindly agreed to have their infants participate in the experiments.

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