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Is the Top Object Adequately Supported by the Bottom Object? Young Infants' Understanding of Support Relations

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Three experiments examined 7.5- to 9.5-month-old infants' ability to distinguish between adequate and inadequate support. The infants in Experiment 1 saw a small box that was centered between and supported by two larger boxes. Neither of the larger boxes alone provided adequate support for the small box. Prior to the experiment, the infants were shown that the small box was either *separate* from or *attached* to the left box. All infants saw the same test event: The right box moved to the right, past the right edge of the small box, which then rested on the left box. The infants who had seen the small box as separate looked reliably longer at the test event, suggesting that they realized that the left box alone did not provide adequate support for the small box and hence were surprised at the small box's failure to fall. The infants in Experiment 2 saw two identical boxes placed side by side. A larger box was placed on the right box with their right edges aligned; the left corner of the large box rested on the left box. The right box alone provided adequate support for the large box but the left box did not. The infants saw two test events. In one (possible) event, the left box moved past the left edge of the large box, which then rested on the right box. In the other (impossible) event, the right box moved past the right edge of the large box, which then rested on the left box. The infants looked reliably longer at the impossible than at the possible event, suggesting that they understood that the left box alone did not provide adequate support for the large box and hence were surprised that the large box did not fall when the right box moved to the side. Experiment 3 tested the generality of these findings using a more difficult problem. The results were negative, indicating that infants' ability to distinguish between adequate and inadequate support is initially limited.

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Adults possess sophisticated beliefs about support relations between objects. These beliefs enable them to place objects safely on tables and shelves, stack objects in cupboards and trunks, carry armfuls of groceries and books, improvise makeshift shelters, balance figurines at the top of Christmas trees and wedding cakes, and so on. Intuitions about support directly or indirectly permeate most of adults' daily interactions with objects.

At what age do infants begin to develop an understanding of support relations between objects? Keil (1979) was the first to investigate this question systematically. Keil examined 18- and 24-month-old infants' understanding of no-support and inadequate-support situations. In the no-support situation, three identical blocks were used; one block was laid across the other two, forming a bridge. The infants saw a series of test events, the last of which was either a possible or an impossible event. In the possible event, the two support blocks were removed and the top block fell. In the impossible event, the two support blocks were removed and the top block remained in place. In the inadequate-support situation, a fourth block was placed upright at the center of the top block. The right support block was removed and the remaining blocks either fell (possible event) or remained in place (impossible event). The results indicated that, in the no-support situation, the infants who saw the impossible event showed more surprise than the infants who saw the possible event. In the inadequate-support situation, in contrast, the infants showed little surprise at either event. These results suggest that infants aged 18 to 24 months (a) expect an object to fall if it has *no* support, but (b) expect an object to remain in place if it has *some* support, even if this support is wholly inadequate.

Piaget (1954) reported observations which are consistent with Keil's (1979) conclusion that young infants are unable to discriminate between adequate and inadequate support.[1] For example, Piaget described how his daughter Lucienne, aged 15 months, had difficulty stacking groups of three and even two objects:

[1] To the best of our knowledge, Piaget (1954) did not directly address the issue of whether young infants understand that an object cannot remain in place without support (no-support situation). Piaget was more concerned with the issue of whether young infants understand that an object that rests on another object is separate from this object. Two observations led Piaget to conclude that it is not until infants are about 9 to 12 months of age that they begin to perceive objects placed on other objects as separate. The first was that when shown an object placed on a slightly larger object (e.g., a matchbox on a book), infants less than 9 months tended to reach for the larger rather than the smaller object, as though the latter were only a part of the former. The second was that when shown an object placed out of reach on a much larger object (e.g., a matchbox placed at the far end of a cushion), infants made no attempt to pull on the larger object to bring the smaller object within reach, as though they did not perceive the two objects as separate. More recent observations indicate that by 8 months of age, if not before, infants reach for objects regardless of the size of the supports on which they are placed (e.g., Bresson, Maury, Pierault-Le Bonniec, & de Schonen, 1977), and pull on supports to bring distant objects within reach (e.g., Willatts, in press).

"Lucienne . . . puts a metal bowl on a wooden pail (smaller than the bowl) and lets go of it. The bowl falls and she begins again, indefinitely" (p. 190).

Lucienne clearly failed to appreciate that the bowl had to be placed in a certain relationship to the pail for the latter to provide adequate support for the former.

Both Keil's (1979) and Piaget's (1954) observations suggest that it is not until after the first year of life that infants begin to distinguish between adequate and inadequate support. However, there are several reasons to question this conclusion. One general reason is that experimental reports published over the last few years indicate that young infants' understanding of the physical world is far more sophisticated than was hitherto suspected. Baillargeon and colleagues (e.g., Baillargeon, 1986, 1987a, 1987b, 1989, in press; Baillargeon & DeVos, 1989; Baillargeon, DeVos, & Graber, 1989; Baillargeon & Graber, 1987, 1988; Baillargeon, Graber, DeVos, & Black, in press; Baillargeon, Spelke, & Wasserman, 1985) have found that infants aged 3 to 8 months are surprisingly adept at representing and reasoning about the existence and properties of occluded objects. For example, Baillargeon (1987b) reported that 7-month-old infants (a) represent the location, height, and compressibility of an object hidden behind a rotating screen, and (b) use this information to predict when the screen will reach the object and stop. Given that infants as young as 7 months of age are able to reason in such sophisticated ways about the interaction of physical objects, one might expect that infants would be able to reason about support relations long before the age of 18 or 24 months.

More specific reasons for questioning Keil's (1979) and Piaget's (1954) conclusion that young infants are unable to discriminate between adequate and inadequate support have to do with the nature of the observations upon which this conclusion was based. Piaget's observations involved infants' manipulations of objects. Young infants could be unsuccessful at stacking, and especially at balancing objects, not because their understanding of support relations is too primitive, but because their manual abilities are too limited. There is certainly evidence in other cognitive areas that infants demonstrate given abilities sooner in visual than in manual tasks. A good case in point is that infants represent the existence of hidden objects as early as 3.5 months of age in visual tasks (e.g., Baillargeon, 1987a; Baillargeon & DeVos, 1989), and yet do not begin to search for hidden objects until 7.5 to 8 months of age (e.g., Diamond, 1985; Harris, in press; Willatts, 1984).

Keil (1979) avoided the potential problems associated with manual tasks by using a visual task to test infants' ability to distinguish between adequate and inadequate support. However, the task Keil devised may have been too difficult. Recall that, in the inadequate-support situation, the infants were presented with an unstable structure made of three blocks: a vertical block standing in the center of a horizontal block whose left end portion was supported by another vertical

block. The infants might have performed better had they been presented—as in Piaget's observation of his daughter Lucienne—with an unstable structure composed of only two objects.[2]

The present experiment was designed to test 7.5- and 9.5-month-old infants' ability to distinguish between adequate and inadequate support. Like Keil, we chose a visual task to examine this ability; and like Piaget, we used an unstable structure involving only two objects.

The infants were assigned to one of two experimental conditions. The infants in both conditions saw the same test event. At the start of this event, the infants saw a small box that was centered between and supported by two larger boxes. Neither larger box alone provided adequate support for the small box. During the event, the right box moved to the right, past the right edge of the small box, and then returned to its initial position. The small box failed to fall when the right box moved aside (it was secured, out of sight, to the back wall of the apparatus). The only difference between the two conditions had to do with the boxes the infants were given to manipulate prior to the experiment. In one condition (three-box condition), the infants were given replicas of the three test boxes: the small box and the two larger boxes. In the other condition (two-box condition), the infants were given two boxes: the right larger box and an oddly shaped box corresponding to the left larger box with the small box attached to its top right corner, just as in the test event (see Figure 1).

Our reasoning was as follows. If the infants in the three-box condition (a) believed that the small box could not remain in place without adequate support, and (b) realized that the left box alone did not provide adequate support for the small box, then they should be surprised when the right box moved aside and the small box, supported only by the left box, failed to collapse. Furthermore, if the infants in the two-box condition (a) believed that the small box was attached to the left box, and hence (b) recognized that the small box was in no way dependent upon the right box for its support, then they should *not* be surprised that the small box remained in place when the right box moved aside. Because an infant's surprise at an event typically manifests itself by prolonged attention to the event, the infants in the three-box condition should look longer at the test event than the

[2] Examination of Keil's (1979) results suggests additional reasons for questioning the conclusion that infants aged 24 months or younger are unable to distinguish between adequate and inadequate support. The means reported by Keil indicate that the 18-month-olds who saw the impossible event were more surprised than those who saw the possible event in both the no-support and the inadequate-support situations, whereas the 24-month-olds who saw the impossible event were more surprised than those who saw the possible event in the no-support, but not in the inadequate-support situation. Unfortunately, the infants' responses to the no-support and the inadequate-support situations were analyzed separately, despite the fact that the same infants saw both situations. Hence, it is not known whether the Age × Situation × Event interaction was indeed reliable. The finding that the younger infants performed reliably better than the older infants would naturally cast doubts upon the appropriateness of the situations tested, and/or the dependent measures used to assess the infants' reactions to the situations.

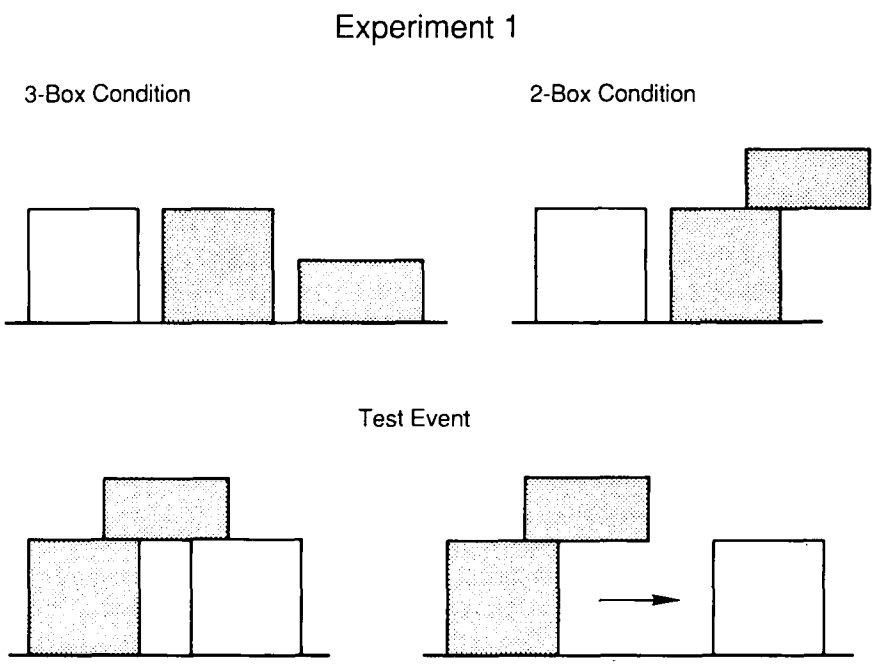

Figure 1. The top half of the figure shows the boxes manipulated by the infants in the three-box and two-box conditions in Experiment 1. The bottom half of the figure is a schematic representation of the test event presented to the infants in both conditions.

infants in the two-box condition. On the other hand, if the infants in the three-box condition (a) expected the small box to remain in place as long as it had *some* support, or (b) believed that the left box alone provided adequate support for the small box, then the infants in the three-box and the two-box conditions should look equally at the test event because neither group of infants would find the event surprising.

There was one difficulty with the design of the experiment. The infants in the three-box condition might look longer at the test event than the infants in the two-box condition, not because they expected the small box to fall and were surprised that it did not, but because they had not had the opportunity to see, during the manipulation phase of the experiment, the odd configuration formed by the left box and the small box. To check this possibility, a third group of infants was included in the design (control condition). These infants were shown the same test event as the other infants. Prior to the test trials, however, the infants were shown (a) the three boxes separately, and (b) the small box held on the top right corner of the left box by the experimenter. We reasoned that if the infants in the three-box condition looked at the test event longer than the infants in the two-box condition simply because they had had no prior experience with the odd configu-

ration of the left box and the small box, then the infants in the control and in the two-box conditions should look about equally at the test event. On the other hand, if the infants in the three-box condition looked longer at the test event because they were surprised that the small box did not collapse, then the infants in the control condition, who knew the small box was not attached to the left box, should also look longer at the test event than the infants in the two-box condition.

There remained one concern with the experimental design. The infants in the three-box, two-box, and control conditions, might look equally at the test event, not because they lacked the ability to discriminate between adequate and inadequate support, but because they lacked additional perceptual and cognitive abilities required by the task. Specifically, the infants might not realize that the boxes shown in the test event were the separate boxes they had manipulated prior to the experiment. They might perceive the test boxes as a single, oddly shaped object and be equally surprised when the right box moved away. However, there were two reasons to doubt such an outcome. The first was the growing evidence from analyses of parents' diaries (e.g., Ashmead & Perlmutter, 1980) and from experimental investigations of location memory (e.g., Baillargeon & Graber, 1988; Baillargeon et al., 1989) and imitation (e.g., Meltzoff, 1988) that infants aged 8 months and older can recall information after an interval considerably longer than that in the experiment. The second was the finding that infants aged 6 months and older perceive independent objects as separate even after the objects are placed next to each other (e.g., Bresson, Maury, Pierault-Le Bonniec, & de Schonen, 1977). Given these results, there was reasonable confidence that the 7.5- to 9.5-month-old infants in the experiment would remember the boxes they had manipulated, and would view the test boxes as an arrangement of these boxes, rather than as a single, oddly shaped object.

EXPERIMENT 1

Method

Subjects. Subjects were 21 healthy, full-term infants ranging in age from 7 months, 20 days to 9 months, 27 days (M = 8 months, 11 days). One additional infant was eliminated from the experiment because of a procedural error. The infants' names 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 travel expenses but were not compensated for their participation.

The infants were randomly divided among the three-box (M = 8 months, 7 days), the two-box (M = 8 months, 23 days), and the control (M = 8 months, 3 days) conditions.

Apparatus. The apparatus consisted of a wooden cubicle 182 cm high, 100 cm wide, and 50 cm deep. The infant faced an opening 36 cm high and 94 cm

wide in the front wall of the apparatus. The floor of the apparatus was painted bright blue and the back and side walls were covered with a brightly lined white contact paper.

Lying across the floor of the apparatus, parallel to the back wall, were two wooden runners, each 0.5 cm high, 100 cm wide, and 3 cm deep. The two runners lay 3 cm apart and the front runner was positioned 25 cm from the front edge of the apparatus. Centered between the two runners and between the two side walls of the apparatus was a slit 82 cm wide and 1 cm deep. Two boxes, each 15 cm high, 15 cm wide, and 7 cm deep, could be moved back and forth along this slit. The boxes were made from balsa wood covered with thick red (left box) or yellow (right box) cardboard and were decorated with brightly colored stars. At the start of the test event, the left and right boxes stood 7 cm apart at the center of the slit, 31.5 cm from the side wall (left wall for the left box, right wall for the right box) and 26 cm from the front edge of the apparatus. Each box was mounted on a plastic square 0.5 cm high, 3 cm wide, and 3 cm deep, which fitted exactly between the two wooden runners. Each plastic square was connected to a handle located until the slit, beneath the floor of the apparatus. Each handle (which consisted of a metal screw, a plastic disk, and a spring) was spring loaded downwards to ensure that the boxes ran smoothly between the two runners.

A small box, 8 cm high, 17 cm wide, and 7 cm deep, was centered between the two larger boxes and was secured to the back wall of the apparatus, out of sight, by means of a metal arm 17 cm long. This small box was made of balsa wood covered with thick red cardboard and was decorated with brightly colored stars. It was hoped that having the small box the same color as the left box, and a different color than the right box, would help the infants in the two-box condition remember the fact that the left box and the small box formed a single, oddly shaped box. The small box was positioned 0.25 cm above the left and right boxes (this gap was necessary to ensure the smooth movement of the right box away from and back under the small box). A yellow paper fringe 1 cm long was attached to the lower edge of the small box in order to conceal the narrow space between this box and the top of the left and right boxes.

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. Two wooden frames, each 182 cm high and 71 cm wide and covered with blue cloth, stood at an angle on either side of the apparatus. These frames served to isolate the infant from the experimental room. A muslin-covered frame 61 cm high and 100 cm wide was lowered in front of the opening in the front wall of the apparatus at the end of each trial.

Event. At the start of each test trial, the small box stood centered between the left and right boxes; the left 5 cm end portion of the small box appeared to rest on the left box, and the right 5 cm end portion of the small box appeared to

rest on the right box. After a 0.5 s pause, the experimenter moved the right box to the right at the approximate rate of 9 cm/s until the box had moved a total of 18 cm (after 5 cm, the right box was no longer beneath the small box). The experimenter paused for 0.5 s and then returned the right box to its initial position beneath the small box. Each event cycle thus lasted about 5 s. Cycles were repeated until the computer signaled that the trial had ended (see below).

To help the experimenter move the right box at a constant rate, a metronome beat softly once per second.

Procedure. During the experiment, the infant sat on his or her parent's lap in front of the apparatus. The infant's head was approximately 95 cm from the boxes. The parent was asked not to interact with the infant while the experiment was in progress. The parent was also instructed to close his or her eyes during the test trials.

To start, the infant was given wooden replicas of the test boxes to manipulate (because these replica boxes were rather heavy, the experimenter simply held the boxes and encouraged the infant to touch them). The boxes were covered with thick cardboard and were decorated with stars and a yellow fringe so that they appeared identical to the test boxes. The infants in the three-box condition were given three boxes to manipulate for a total of about 10 s; these were the small box and the left and right boxes. The infants in the two-box condition were given two boxes to manipulate, also for about 10 s; these were the right box, and a single box corresponding to the small box attached to the top right corner of the left box. Finally, the infants in the control condition were given the test boxes to manipulate in four segments lasting about 5 s each. These segments involved (1) the small box and the left and right boxes; (2) the right box, and the small box held by the experimenter on the top right corner of the left box; (3) same as (1); and (4) same as (2).

After manipulating the boxes, all infants saw the test event described above on four successive trials. Each test trial ended when the infant either (a) looked away from the event for 2 consecutive seconds after having looked at it for at least 4 cumulative seconds or (b) looked at the event for 30 cumulative seconds without looking away for 2 consecutive seconds.

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 did not know to which condition the infant was assigned. Each observer held a button box connected to a MICRO/PDP–11 computer and depressed the button when the infant attended to the events. Interobserver agreement was calculated for each trial on the basis of the number of seconds that the observers agreed on the direction of the infant's gaze out of the total number of seconds that the trial lasted. Disagreements of less than 0.1 s were ignored. Agreement in this experiment and in the subsequent experiments averaged 92% or more per trial per infant. The looking times recorded by the primary observer were used to determine the end of the trials.

Results

Figure 2 shows the mean looking times at the test event of the infants in the three-box, two-box, and control conditions. It can be seen that the infants in the three-box and the control conditions looked longer at the test event than the infants in the two-box condition.

Planned contrasts were conducted to compare the looking times of the infants in the three conditions to the test event. These contrasts revealed that (a) the infants in the three-box condition looked reliably longer at the test event (M = 22.3) than the infants in the two-box condition (M = 16.2), $F(1, 18) = 4.57$, $p < .05$; (b) the infants in the control condition looked reliably longer at the test event (M = 23.2) than the infants in the two-box condition, $F(1, 18) = 6.12$, $p < .05$; and finally, (c) the infants in the three-box and the control conditions looked about equally at the test event, $F(1, 18) = 0.11$.

The looking times of the infants in the three conditions were also compared by means of a 3 × 4 mixed model analysis of variance (ANOVA), with Condition (three-box, two-box, or control condition) as the between-subjects factor and Test Trial (first, second, third, or fourth test trial) as the within-subjects factor. The Condition × Test Trial interaction was not significant, $F(1, 54) = 1.54$, $p > .05$, suggesting that the pattern described above did not differ reliably across trials. The only significant effect was that of test trial, $F(3, 54) = 7.06$, $p < .0005$, indicating that the infants looked reliably less as the experiment progressed.

Discussion

The infants in the three-box and the control conditions in Experiment 1 looked reliably longer at the test event than the infants in the two-box condition. These results suggest that the infants in the three-box and the control conditions (a) believed that the small box was supported by the left and right boxes; (b) understood that the left box alone did not provide adequate support for the small

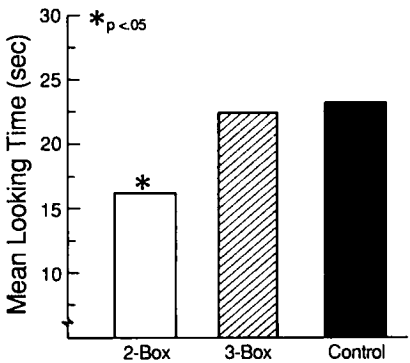

Figure 2. Mean looking times of the infants in the three-box, two-box, and control conditions in Experiment 1 at the test event.

box; and hence (c) were surprised that the small box did not fall when the right box was moved aside. Thus, contrary to what Keil (1979) and Piaget (1954) claimed, it appears that infants as young as 7.5 to 9.5 months of age are capable of determining, at least in simple situations, whether an object is adequately supported by the object upon which it rests.

The fact that the infants in the two-box condition looked at the test event reliably less than the infants in the other two conditions suggests that they (a) believed that the small box was firmly attached to or part of the left box, and so (b) expected the small box to remain in its place when the right box was moved aside. The brief manipulation phase at the start of the experiment was thus sufficient for the infants to form lasting representations of the test boxes, representations which they made use of in interpreting the test event.

EXPERIMENT 2

The results of Experiment 1 showed that 7.5- to 9.5-month-old infants can distinguish, at least in simple situations, between adequate and inadequate support. Experiment 2 was designed to confirm this finding, using a somewhat different method.

To start, the infants saw two identical boxes placed side by side. A larger box was placed on the right box, with their right edges aligned; the overhanging left corner of the larger box rested on the left box (see Figure 3). The right box alone provided adequate support for the large box, but the left box did not. The infants saw two test events. In one (possible) event, the left box moved to the left, past the left edge of the large box, and then returned to its initial position. In the other (impossible) event, the right box moved to the right, past the right edge of the large box, and then returned to its initial position. In both events, the large box remained in place (it was secured, out of view, to the back wall of the apparatus).

Our reasoning was as follows. If the infants (a) understood that the large box could not remain in place without adequate support, and (b) realized that the right but not the left box alone provided adequate support for the large box, then they should be surprised in the impossible event when the large box, supported only by the left box, failed to collapse. On the other hand, if the infants (a) expected the large box to remain in place as long as it had some support, or (b) believed that the right or the left box alone provided adequate support for the large box, then they should look equally at the two test events, because neither event would seem surprising.

There were foreseeable problems with the design of our experiment. The infants might look reliably longer at the impossible than at the possible event, not because they expected the large box to collapse and were surprised that it did not, but because (a) they preferred the movement of the right box to that of the left box; (b) they found the perceptual configuration of the boxes in the impossible event more interesting than that in the possible event; or (c) they perceived the

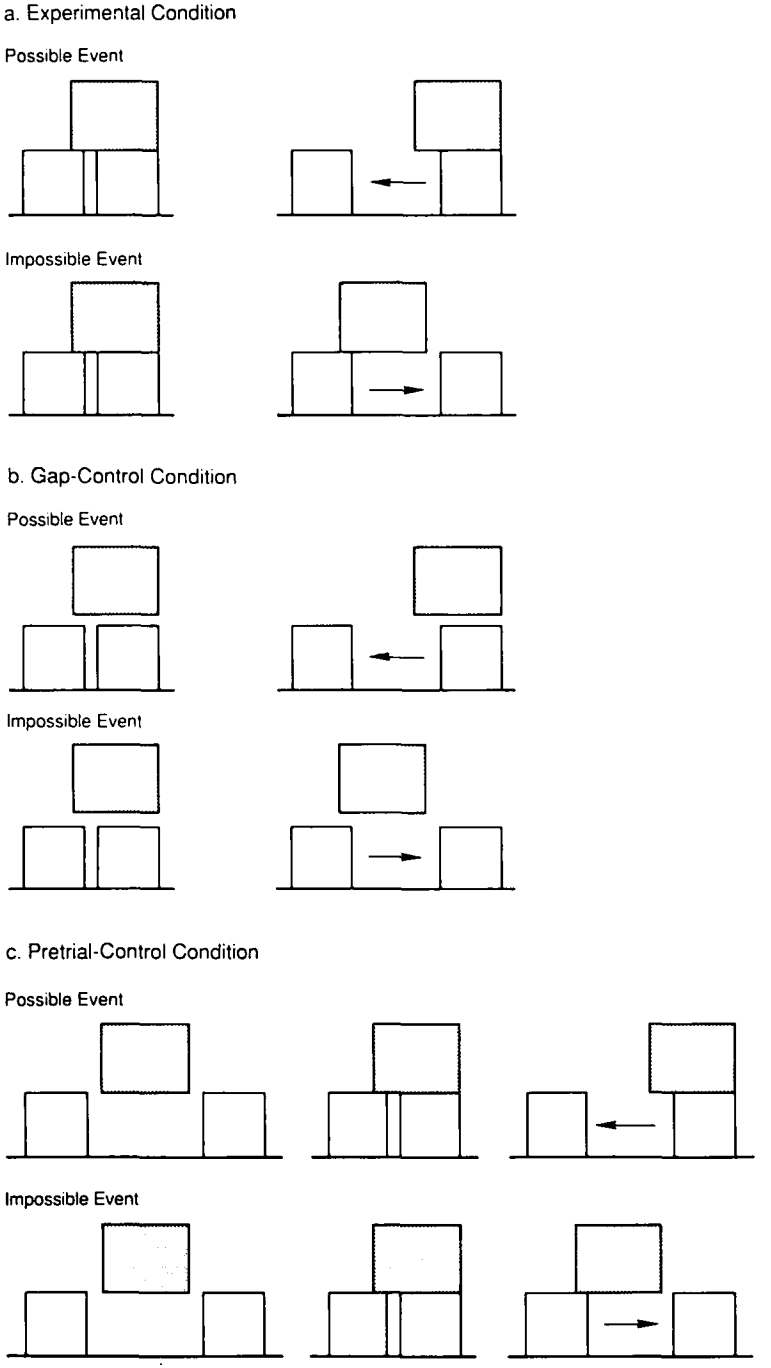

Figure 3. Schematic representation of the test events shown to the infants in the experimental, the gap-control, and the pretrial-control conditions in Experiment 2.

arrangement of the large box and the left box in the impossible event to be novel (in daily life, infants would be unlikely to have encountered such an arrangement, which was only achieved through trickery). To test these possibilities, we ran two control conditions that were similar to the experimental condition, except that the infants were provided with information that the large box was not in fact supported by the smaller boxes beneath it. In one control condition, this information was made available to the infants throughout the test trials; in the other, the information was given only at the start of each test trial. The infants in the first control condition (gap-control condition) saw the same test events as the infants in the experimental condition except that the large box was raised a few centimeters so that there was a narrow gap between the large box and the smaller boxes under it. The infants in the second control condition (pretrial-control condition) saw exactly the same test events as the infants in the experimental condition. However, each test trial was preceded by a 2-second pretrial during which the smaller boxes were positioned to the left and right of the large box, which thus appeared suspended in midair. At the end of this pretrial, the smaller boxes were slid under the large box and the trial proceeded as in the experimental condition (see Figure 3).

Our reasoning was as follows. If the infants in the experimental condition looked longer at the impossible event because they preferred the movement of the right box to that of the left box, or because they found the configuration of the boxes in the impossible event more interesting than that in the possible event, or because they viewed the arrangement of the large box and the left box in the impossible event to be novel, then the infants in the control conditions should also look longer at the impossible event because most or all of these factors would also affect their looking behavior. On the other hand, if the infants in the experimental condition looked longer at the impossible event because they expected the large box to fall and were surprised that it did not, then the infants in the control conditions should look equally at the two test events—provided that they understood the information made available to them.

There were several ways for the infants in the control conditions to construe the information they were given. For example, they could have concluded that the large box was supported by neither the right nor the left box but was held in place by some other, hidden means of support (this is of course what adults would have inferred in the situation). Alternatively, they could have realized that the large box was supported by neither the left nor the right box but have been at a loss to explain why the large box remained suspended in midair. For the purposes of the present experiment, it did not matter whether the infants in the control conditions succeeded in generating an explanation for the large box's stable position. What we hoped to establish was that the infants in the experimental condition looked longer at the impossible event because they expected the large box to fall and were surprised that it did not. We thought that such an inference would be warranted if the infants in the control conditions looked

equally at the impossible and the possible test events, however they came to do so.

Method

Subjects. Subjects were 42 healthy, full-term infants ranging in age from 7 months, 19 days to 9 months, 22 days (M = 8 months, 21 days). One additional infant was eliminated from the experiment because of procedural error. One third of the infants was randomly assigned to the experimental condition (M = 8 months, 19 days), one third to the gap-control condition (M = 8 months, 24 days), and one third to the pretrial-control condition (M = 8 months, 21 days).

Apparatus. The apparatus used in Experiment 2 was similar to that in Experiment 1 with a few exceptions. The left and right boxes stood 3 cm as opposed to 7 cm apart; they were identical to those in Experiment 1 except that the right box was covered with red instead of with yellow cardboard. The small box used in Experiment 1 was replaced by a larger box 17 cm high, 21 cm wide, and 7 cm deep, and covered with yellow cardboard. As in Experiment 1, all boxes were decorated with brightly colored stars.

Experimental Condition Events

Impossible Test Event. At the start of the event, the large box was positioned 0.25 cm above the right box with their right edges aligned; the left 3 cm portion of the large box was positioned 0.25 cm above the left box. A yellow paper fringe 1 cm long was attached to the lower edge of the large box to conceal the gap between this box and the top of the left and right boxes. As in Experiment 1, the gap was necessary to ensure the smooth movement of the left and right boxes away from and back under the large box.

After a 0.5 s pause, the experimenter moved the right box to the right at the approximate rate of 9 cm/s until it had covered a distance of 18 cm (after 15 cm, the right box was no longer beneath the large box, which appeared to be supported exclusively by the left box). Following another 0.5 s pause, the experimenter returned the right box to its initial position beneath the large box. Each full cycle of movement thus lasted about 5 s. Cycles were repeated until the computer signaled that the trial had ended (see below).

Possible Test Event. The possible test event was identical to the impossible test event except that the experimenter moved the left box instead of the right box (after the left box was moved 3 cm, the large box appeared to rest exclusively on the right box).

Gap-Control Condition Events

The impossible and possible test events shown to the infants in the gap-control

condition were identical to those shown to the infants in the experimental condition except that the large box was raised 2.5 cm above the left and right boxes. The distance between the bottom of the large box's fringe and the top of the left and right boxes was 1.5 cm.

Pretrial-Control Condition Events

The impossible and possible test events shown to the infants in the pretrial-control condition were identical to those shown to the infants in the experimental condition with one exception. At the start of each test trial, the infants were given a pretrial during which the left box was positioned 3.5 cm to the left, and the right box 3.5 cm to the right of the large box, which then appeared to be suspended in midair without any visible means of support. After the computer signaled that the infant had looked at the display for 2 cumulative seconds, the experimenter moved the left and right boxes simultaneously to their starting positions under the large box, and proceeded as described above.

Procedure

As in Experiment 1, the infant sat on his or her parent's lap in front of the apparatus. Prior to the beginning of the experiment, each infant manipulated wooden replicas of the three test boxes for a few seconds. 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 also instructed to close his or her eyes.

Each infant participated in a two-phase procedure consisting of a familiarization and a test phase. These two phases are described in turn.

Familiarization Phase. In a pilot study, 8 infants (M = 8 months, 27 days) saw the impossible and possible test events used in the experimental condition on alternate trials until they completed three pairs of test trials (order was counterbalanced). The infants looked reliably longer at the impossible (M = 11.8) than at the possible (M = 8.1) event in their *first* look on each trial, $F(1, 21) = 9.30$, $p < .01$, but not in their *total* looks on each trial, $F(1, 35) = 0.00$ (impossible: M = 17.0; possible: M = 16.9). These results were similar to those of Experiment 1 in that the infants showed a reliable preference for the impossible over the possible event, suggesting that they could discriminate between adequate and inadequate support; however, the results were weaker than those of Experiment 1 in that the infants' preference for the impossible event affected only their first look on each trial.

Why did the infants in our pilot experiment express a preference for the impossible event in their first look, but not in their total looks on each trial? We speculated that the alternating movement of the left and the right boxes tended to draw the infants' attention away from the large box. (There was no such problem in Experiment 1 because only the right box was moved.) The infants were

initially surprised at the large box's failure to fall but rapidly became distracted by the left or the right box's movement. We hypothesized that first showing the large box alone might help focus the infants' interest in this box, leading to reliably longer total looks at the impossible than the possible event. Accordingly, a few additional infants were tested with the same procedure as before with one exception: Prior to the test trials, the infants received a familiarization trial in which they saw the large box alone (the left and the right boxes were removed for this trial). For some of the infants, the large box rested on the floor of the apparatus; for others, the large box appeared suspended in midair, in the same position it occupied in the test events. Somewhat surprisingly, it was found that the latter manipulation was effective but the former was not. Whereas the infants who saw the large box on the floor of the apparatus looked equally (in their total looks) at the impossible and possible test events, as did the infants in the initial pilot experiment, the infants who saw the large box suspended in midair showed a marked preference for the impossible event. These results suggested that in order to enhance the infants' preference for the impossible event, it was necessary not only to call their attention to the large box, but also to focus their interest on the issue of its support. (This issue will be explored further in the Discussion section.)

On the basis of these preliminary results, we decided to give each infant in Experiment 2 a familiarization trial in which the large box appeared alone, apparently suspended in midair. This trial ended when the infant (a) looked away from the display for 2 consecutive seconds after having looked at it for at least 10 cumulative seconds, or (b) looked at the display for 30 cumulative seconds without looking away for 2 consecutive seconds.

Test Phase. Following the familiarization trial, the infants in the experimental and the two control conditions saw the impossible and the possible test events described above. The infants saw the two test events on alternate trials until they had completed three pairs of test trials. Half of the infants in each condition saw the impossible event first, and half saw the possible event first. Each test trial ended when the infant (a) looked away from the event for 2 consecutive seconds after having looked at it for at least 4 cumulative seconds, or (b) looked at the event for 30 cumulative seconds without looking away for 2 consecutive seconds.

Results

Figure 4 shows the mean looking times at the impossible and possible events of the infants in the experimental, gap-control, and pretrial-control conditions. It can be seen that the infants in the experimental condition looked longer at the impossible than at the possible event, whereas the infants in the gap- and the pretrial-control conditions looked about equally at the two events.

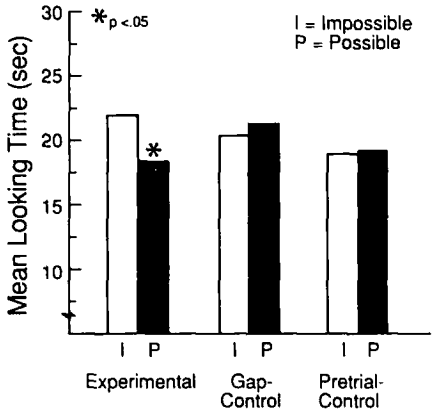

Figure 4. Mean looking times of the infants in the experimental and the gap- and pretrial-control conditions in Experiment 2 at the impossible and the possible events.

Planned contrasts were conducted to compare the mean looking times of the infants in each condition at the impossible and possible test events. These contrasts revealed that (a) the infants in the experimental condition looked reliably longer at the impossible (M = 21.9) than at the possible (M = 18.3) event, $F(1, 195) = 5.68, p < .02$; (b) the infants in the gap-control condition tended to look equally at the impossible (M = 20.3) and possible (M = 21.3) events, $F(1, 195) = 0.42$; and (c) the infants in the pretrial-control condition also tended to look equally at the impossible (M = 19.0) and possible (M = 19.2) events, $F(1, 195) = 0.008$.

The infants' looking times were also analyzed by means of a 3 × 3 × 2 mixed model ANOVA with Condition (experimental, gap-control, and pretrial-control conditions) as the between subjects factor and with Test Pair (first, second, or third pair of test trials) and Event (impossible or possible test event) as the within-subjects factors. The Condition × Test Pair × Event interaction was not significant, $F(4, 195) = 1.64, p > .05$, indicating that the pattern described above did not differ reliably across test pairs. The only significant effect was that of test pair, $F(2, 195) = 70.56, p = .0001$, showing that the infants looked reliably less as the experiment progressed.

Discussion

The results of Experiment 2 indicate that the infants in the experimental but not the control conditions looked reliably longer at the impossible than at the possible event. These results provide evidence that the infants in the experimental condition looked longer at the impossible event, not because they found the movement of the right box more interesting than that of the left box, nor because they preferred the perceptual configuration of the boxes in the impossible event to that in the possible event, nor because they perceived the arrangement of the

large box and the left box in the impossible event to be novel, but because they expected the large box to fall, and were surprised that it failed to do so. This finding suggests that the infants in the experimental condition (a) believed that the large box was supported by the left and right boxes, and (b) understood that the right but not the left box alone provided adequate support for the large box. Thus, like the results of Experiment 1, the results of Experiment 2 indicate that infants aged 7.5 to 9.5 months are able to judge, at least in simple situations, whether an object is adequately supported or not.

How did the infants in Experiment 2 interpret the familiarization event shown at the beginning of the experiment? At least three alternatives are possible. The first is that the infants felt no puzzlement at the event, readily admitting that the large box could rest in midair without support. The second is that the infants were surprised by the event (suggesting that they understood that no object can remain stable without support) but were unable to generate an explanation for the large box's failure to collapse. The third is that the infants immediately inferred, upon seeing the event, that some hidden support held the large box in its stable position.

We believe that the first and third alternatives are unlikely for the following reason. If the infants in Experiment 2 showed little surprise at the familiarization event because (a) they readily believed that the large box could remain stable without support, or (b) they readily inferred that the large box received support from some hidden means, it would be difficult to understand why the infants in the three-box and the control conditions in Experiment 1, and the infants in the experimental condition in Experiment 2, reacted with marked surprise at the impossible events they were shown, and did so consistently across test trials. (Recall that there was no reliable interaction involving the Test Trial/Test Pair factor in either experiment.) If the first or third alternative had been correct, one would have expected these infants to demonstrate at most a fleeting interest in the impossible events. This line of reasoning suggests that the second alternative mentioned above is the most likely: That is, the infants were surprised or puzzled by the large box's failure to fall, but they were unable to produce an explanation for this failure. Therefore, they viewed the large box as floating, inexplicably, in midair.

How did the infants in the experimental and the control conditions in Experiment 2 integrate the information provided in the familiarization event with that conveyed in the test events? Let us begin with the infants in the control conditions. The test results suggest that these infants (a) were aware that the large box received no support from the left and right boxes, and (b) just as in the familiarization event, were puzzled by the large box's inexplicable failure to collapse. In contrast to the infants in the control conditions, the infants in the experimental condition (a) believed that the large box was now supported by the boxes beneath it, and (b) did not abandon this belief in the impossible event when the right box was moved aside leaving the large box (inadequately) supported by the left box.

The foregoing discussion gives rise to two questions. First, why did the experimental infants assume that the large box was supported by the left and right boxes, whereas the pretrial-control infants did not? One hypothesis involves memory. Following the familiarization event, there was a 2- to 3-minute pause during which the experimenter installed the left and right boxes under the large box. It could be that the experimental infants forgot having seen the large box suspended in midair during this interval so that their responses were unaffected by this event; the pretrial-control infants, in contrast, saw the large box suspended in midair at the beginning of each test trial. This hypothesis is unlikely because (a) it is inconsistent with the pilot data reported earlier, and (b) as mentioned in the introduction to Experiment 1, there is now evidence that infants aged 7 months and older can recall information for intervals considerably longer than that used in Experiment 2 (e.g., Ashmead & Perlmutter, 1980; Meltzoff, 1988). A second, very intriguing hypothesis is that the infants were able to distinguish, at some level, between events that could and could not modify the large box's support. Thus, the infants in the pretrial-control condition realized that sliding the left and right boxes under the large box could *not* have altered its support: Whatever held the large box in place before the left and right boxes were introduced must still do so. (This is of course what adults would have concluded in the situation.) In marked contrast, the infants in the experimental condition understood, upon noticing the newly installed left and right boxes beneath the large box, that the former *could* be supporting the latter. (Even adults could not have known for certain, at the start of the test trials, whether the large box was supported by the left and right boxes or whether it was supported, as before, by hidden means.)

The second question raised by the description of the infants' interpretation of the test trials is the following: Why did the experimental infants continue to assume that the large box was supported by the boxes beneath it after they saw the impossible event? Upon seeing this event, adults would have immediately inferred that the large box was not, indeed could not be supported by the left and right boxes. The test results suggest that the infants never revised their assumption that the large box was supported by the boxes under it. (Had they done so, one would have expected their looking pattern across trials to approximate that of the control infants.) Rather, it appears as though the experimental infants were thinking something along the lines of: "I am amazed that this left box can support the large box . . . I could have sworn it was insufficient for the task."[3]

[3] The same argument could be made about the results obtained with the infants in the three-box and the control conditions in Experiment 1: These infants did not immediately conclude, upon seeing that the small box did not fall, that it must be attached to the left box, or supported by some hidden means. Their looking patterns did not differ reliably across trials, suggesting that they remained puzzled by the event ("I could have sworn this small box received too little support to remain stable").

EXPERIMENT 3

The results of Experiments 1 and 2 suggest that, by 7.5 and 9.5 months of age, infants are able, in some situations at least, to judge whether an object placed upon another object is adequately supported or not. Experiment 3 began to examine how general or how sophisticated this ability is. In the impossible events used in Experiments 1 and 2, the infants saw a symmetrical object supported at its corner by the corner of another object. To adults, it is perfectly obvious that the top object in these events is inadequately supported and should fall. Would infants perform as well with an impossible event that appeared, intuitively, slightly less obvious? In the impossible event used in Experiment 3, the infants saw an asymmetrical object supported on nearly half of its bottom surface by the entire top surface of another object.

The design of Experiment 3 was similar to that of Experiment 2 with two exceptions: (a) the left and right boxes were slightly narrower, and (b) the large box was replaced by a right triangle (see Figure 5). One leg of this triangle was horizontal and just covered the top surfaces of the left and right boxes; the other, vertical leg was aligned with the right edge of the right box. Because the triangle was asymmetrical, its center of gravity did not lay above the center of its bottom edge, as was the case with the rectangular boxes used in Experiments 1 and 2,

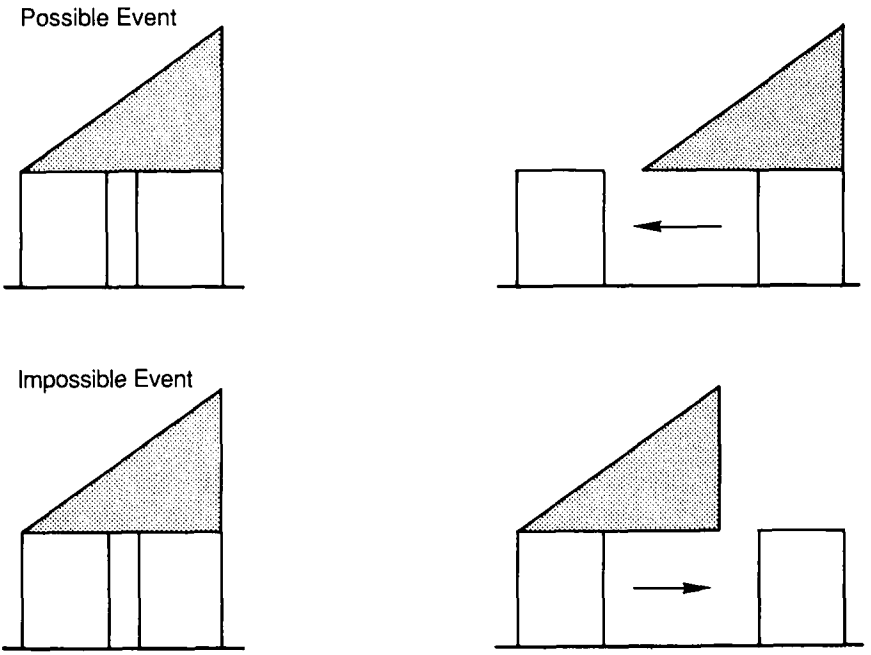

Figure 5. Schematic representation of the test events shown to the infants in Experiment 3.

but was instead displaced toward the triangle's right edge. Therefore, the right box alone provided adequate support for the triangle, but the left box did not.

Our reasoning was as follows. If the infants understood that (a) the triangle could not remain in place without adequate support, and (b) the right box alone provided adequate support for the triangle but the left box did not, then they should be surprised in the impossible event when the triangle, supported only by the left box, failed to collapse. Therefore, they should look longer at the impossible than at the possible event. On the other hand, if the infants (a) believed that the triangle would remain in place as long as it received some support, or (b) falsely determined that the right or the left box alone provided adequate support for the triangle, then they should look equally at the two test events because neither event would seem surprising.

Method

Subjects. Subjects were 18 healthy, full-term infants ranging in age from 7 months, 19 days to 9 months, 27 days (M = 8 months, 11 days). One additional infant was eliminated from the experiment because he failed to attend to the test events.

Apparatus and Events. The apparatus and events used in Experiment 3 were identical to those used in the experimental condition in Experiment 2 with two exceptions. First, the left and right red boxes were replaced by two narrower boxes, each 16 cm high, 12 cm wide, and 7 cm deep. At the start of each test event, the two boxes stood 4 cm apart at the center of the apparatus, 36 cm from the side walls (left wall for the left box, right wall for the right box), and 26 cm from the front edge of the apparatus. Second, the large box was replaced by a right triangle 20 cm high (vertical leg), 28 cm wide (horizontal leg), and 7 cm deep. This triangle was made of balsa wood covered with thick yellow cardboard and was decorated with brightly colored dots. The triangle was positioned 0.25 cm above the tops of the left and right boxes, to ensure the smooth movement of these boxes away from and back under the triangle. A yellow paper fringe 1 cm long was attached to the lower edge of the triangle to conceal the gap separating the triangle and the left and right boxes.

Procedure. The procedure used in Experiment 3 was identical to that used in the experimental condition in Experiment 2. To start, the infants manipulated wooden replicas of the triangle and the left and right boxes for a few seconds. Next, each infant received a familiarization trial in which the triangle was shown alone, suspended in midair. Following this trial, each infant saw the impossible and possible events on alternate trials (order was counterbalanced) until he or she had completed three pairs of test trials.

Results

The infants' looking times were analyzed by means of a 3 × 2 mixed model ANOVA with Test Pair (first, second, or third pair of test trials) and Event (impossible or possible event) as the within-subjects factors. The main effect of event was not significant, $F(1, 17) = 0.29$, indicating that the infants tended to look equally at the impossible ($M = 18.2$) and the possible ($M = 18.9$) events. The only significant effect was that of pair, $F(2, 34) = 14.82$, $p < .001$, indicating that the infants looked reliably less as the experiment progressed.

At least two interpretations are consistent with the finding that the infants tended to look equally at the impossible and the possible events. One is that the infants believed that *either* the left or the right box alone provided adequate support for the triangle and so viewed both test events as possible events. The other is that the infants assumed that *neither* the left nor the right box alone provided adequate support for the triangle, and so viewed both events as impossible events. Comparison of the results of Experiment 3 with those of the experimental condition in Experiment 2 provides evidence for the first of these interpretations. Analysis of the familiarization trial data revealed no reliable difference between the looking times of the infants in Experiment 2 to the large box ($M = 17.2$) and the looking times of the infants in Experiment 3 to the triangle ($M = 16.9$), $F(1, 30) = 0.01$. Analysis of the test trials data yielded a significant Experiment × Event interaction, $F(1, 90) = 5.43$, $p < .025$. Follow-up comparisons confirmed that the infants in Experiment 2 looked reliably longer at the impossible ($M = 21.9$) than at the possible ($M = 18.4$) event, $F(1, 90) = 6.58$, $p < .02$, whereas the infants in Experiment 3 looked about equally at the two events, $F(1, 90) = 0.69$ (impossible: $M = 18.2$; possible: $M = 18.9$). Additional comparisons revealed that the mean looking time of the infants in Experiment 2 at the impossible event was reliably longer than that of the infants

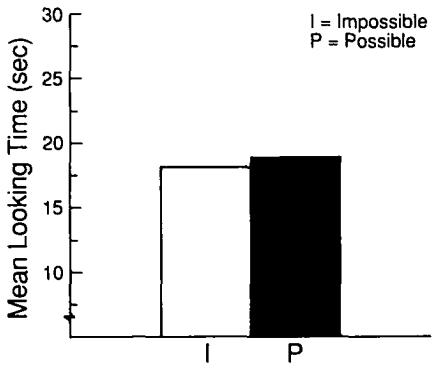

Figure 6. Mean looking times of the infants at the impossible and possible events in Experiment 3.

in Experiment 3 at either the impossible event, $F(1, 90) = 8.23$, $p < .006$, or the possible event, $F(1, 90) = 5.24$, $p < .025$. These findings suggest that the infants in Experiment 3 regarded the two test events they were shown as possible events: They believed that the left or the right box alone provided adequate support for the triangle.

Discussion

In contrast to the infants in the experimental condition in Experiment 2, who looked reliably longer at the impossible than at the possible event, the infants in Experiment 3 tended to look equally at the two events. These results suggest that 7.5- to 9.5-month-old infants' ability to distinguish between adequate and inadequate support is limited. Infants perform well when presented with what, to adults, are extreme instances of inadequate support, and perform less well with less obvious (though still clear-cut) instances.

CONCLUSION

The infants in the three-box and the control conditions in Experiment 1, and those in the experimental condition in Experiment 2, (a) believed that the left and right boxes supported the top box; (b) understood that the left box alone did not provide adequate support for the top box; and therefore (c) were surprised that the top box did not collapse when the right box was moved aside. These findings indicate that, contrary to what Keil (1979) and Piaget (1954) claimed, infants as young as 7.5 to 9.5 months of age are able to determine, in simple situations at least, whether an object is adequately or inadequately supported.

These results raise three important questions. First, at what age do infants become capable of distinguishing between adequate and inadequate support? Would infants aged 5, or even 3 months, show surprise at the impossible events used in Experiments 1 and 2? Second, how do infants come by their intuitions about support? Are these intuitions based upon infants' *observations* of instances of adequate and inadequate support in their environment (e.g., caretakers placing objects on tables or dropping objects, objects remaining stable on shelves or rolling off sofas)? Or do infants' *own manipulations* of objects play a crucial role in the elaboration of these intuitions? One could envisage the following developmental sequence. As infants grasp and release objects in the first few months of life, they come to realize that objects cannot remain stable without support: The rattles, pacifiers, and bottles infants release in midair invariably fall. As infants learn to sit and gain experience at placing objects on surfaces, at about 5 or 6 months of age, they come to recognize that objects fall not only when their support is withdrawn, but also when it is inadequate: The bowls, cups, and toys infants place on the edges of tables typically fall, just as though they had no

support. This hypothesis makes predictions about the age at which one might expect infants to reason successfully about no-support situations (about 3 months of age), and about inadequate-support situations of the type used in Experiments 1 and 2 (about 6 months of age). Experiments are currently under way to test this sequence. The hypothesis also makes interesting predictions about the kind of experiences necessary for the development of intuitions about support relations between objects. For example, one might expect infants who are given early opportunity to practice placing objects on surfaces (e.g., infants who are regularly seated at a table at 3 or 4 months of age) to show an earlier understanding of the distinction between adequate and inadequate support than infants who do not receive such opportunity until later.

The third question raised by the results of the present experiments is the following: How do infants go about deciding whether an object is adequately supported or not? Technically, a box "A" placed on a stable box "B" (as in the situations used in Experiments 1–3) will remain in position if a line drawn through A's center of gravity falls within B's boundaries; if the line does not fall within B, A will collapse. Although most adults may be unable to articulate this rule, it is likely that they use it, implicitly, in their judgments. Did the infants we tested use a similar rule? The results of these experiments suggest two possibilities. The first is that the infants did appreciate, implicitly, that they needed to consider the top object's center of gravity in deciding whether it was adequately supported, but that their ability to estimate *where* the top object's center of gravity lay was very crude. In Experiments 1 and 2, the infants were presented with symmetrical objects which apparently gave them little difficulty. However, in Experiment 3, the infants were presented with an asymmetrical object and, on the present view, failed to realize that the object's center of gravity did not lay above the center of the object's bottom edge, as with the symmetrical objects, but was instead displaced toward the object's right edge.

The second possibility suggested by the results of the present experiments is that the infants' decisions about support were based on primitive rules that made no reference to the top object's center of gravity. For example, the infants may have relied on a rule that an object placed on another object is likely to fall if only a small portion of its bottom surface is supported. This rule would predict that the top object would fall in the impossible events in Experiments 1 and 2, where less than one third of the top object's bottom surface was supported (Experiment 1: 29%; Experiment 2: 14%), but would *not* fall in the impossible event in Experiment 3, where nearly half (43%) of the top object's bottom surface was supported. Alternatively, the infants may have relied on a rule that an object placed on another object is likely to remain in position if (a) the bottom surface of the top object is in (nearly) full contact with the bottom object, or (b) the top surface of the bottom object is in (nearly) full contact with the top object. This second rule, like the first, would predict that the top object would fall in the impossible

events in Experiments 1 and 2 because neither (a) nor (b) was true, but would *not* fall in the impossible event in Experiment 3 because (b) was true.[4]

Future research will need to determine what rules infants use to judge whether an object placed on another object is adequately supported, and how these rules improve with age. With respect to issues of development, investigators will again need to establish whether changes in the sophistication and accuracy of the rules infants use reflect advances that are derived from (a) their observation and interpretation of support situations, or (b) their manipulations of objects (e.g., learning to stack or balance various toys). Piaget's (1954) anecdotal evidence that his 15-month-old daughter, Lucienne, had difficulty stacking two different objects (a bowl and a pail), suggests that infants' knowledge of support may at some point in development outstrip their ability to translate this knowledge into actions. One would not be surprised to find out that infants fail to stack or balance objects in some situations, not because their intuitions about support are too limited, but because their motor coordination is still too primitive.

Additional directions for future research include broadening the scope of the situations investigated to encompass problems in which more complex arrangements of objects are used (e.g., one object placed on two or more objects, three or more objects placed one above the other, and so on), as well as problems involving objects of different size, shape, and density. Comparison of the rules infants use when confronted with different types of support problems will help researchers assess how consistent or integrated are infants' intuitions about support. The discovery that these intuitions, far from being piecemeal or inconsistent, are organized into some coherent conceptual framework, would provide suggestive evidence for the recent view of concepts as embedded in theories (e.g., Carey, 1985; Keil, 1986; Murphy & Medin, 1985).

The results of Experiments 1 and 2 point to hitherto unsuspected abilities on the part of young infants to reason about support relations between objects. Much remains to be uncovered about the origins and development of these abilities. New experimental methods can doubtless be designed that will provide converging evidence for the preliminary findings reported here, and will make it possible to investigate in further detail this important facet of infants' "naive physics."

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[4] In describing these rules, we are referring to the responses of (a) the infants in the three-box and the control conditions in Experiment 1 to the test event they were shown; (b) the infants in the experimental condition in Experiment 2 to the impossible event; and (c) the responses of the infants in Experiment 3 to the impossible event. But the rules can also be used to account for the responses of the infants in the experimental condition in Experiment 2 and the infants in Experiment 3 to the possible event they were shown.

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