Research Article

INFANTS' KNOWLEDGE ABOUT OCCLUSION AND CONTAINMENT EVENTS: A Surprising Discrepancy

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Abstract—*The present research examined whether infants acquire general principles or more specific rules when learning about physical events. Experiments 1 and 2 investigated 4.5-month-old infants' ability to judge how much of a tall object should be hidden when lowered behind an occluder versus inside a container. The results indicated that at this age infants are able to reason about height in occlusion but not containment events. Experiment 3 showed that this latter ability does not emerge until about 7.5 months of age. The marked discrepancy in infants' reasoning about height in occlusion and containment events suggests that infants sort events into distinct categories, and acquire separate rules for each category.*

Recent research indicates that by 2.5 months of age, infants have already begun to acquire expectations about physical events (e.g., Aguiar & Baillargeon, 1999; Hespos & Baillargeon, in press; Spelke, Breinlinger, Macomber, & Jacobson, 1992; Wilcox, Nadel, & Rosser, 1996). What is the nature of the learning mechanism that makes possible these acquisitions, and what constraints does it place on the knowledge infants acquire? In the experiments we report here, we asked whether infants acquire general expectations that are applied to all relevant events, or specific expectations that are kept tied to the events during which they are first acquired.

The point of departure for our research was the finding that infants aged 3.5 months and older realize that the height of an object relative to that of an occluder determines whether the object should be fully or only partly hidden when behind the occluder (e.g., Baillargeon & DeVos, 1991). Our experiments examined whether young infants also realize that the height of an object relative to that of a container determines whether the object should be fully or only partly hidden when inside the container.

Experiment 1 compared 4.5-month-old infants' ability to judge how much of a tall object should be hidden when placed behind a short or tall occluder (occluder condition) or inside a short or tall container (container condition). Based on prior research, we expected the infants in the occluder condition to be successful at judging how much of the object should be hidden. The question of interest was whether the infants in the container condition would also be successful. Because the outcomes in the occluder and container conditions were predictable from the same general principles, we reasoned that evidence that the infants succeeded in both conditions would suggest that infants acquire general expectations that are applied to all relevant events. In contrast, evidence that the infants succeeded in the occluder but not the container condition would suggest that infants perceive occlusion and containment as distinct event categories and do not generalize expectations from one category to the other.

EXPERIMENT 1

The infants were tested using the violation-of-expectation method (e.g., Baillargeon, 1998). In a typical experiment conducted with this method, infants see two test events: an *expected* event that is consistent with the physical expectation being examined in the experiment and an *unexpected* event that violates this expectation. If appropriate controls are used, longer looking at the unexpected than at the expected event provides evidence that infants detect the violation in the unexpected event and thus possess the expectation under examination.

The infants in the *container* condition saw a tall and a short test event (see Fig. 1). At the start of each event, a hand grasped a knob at the top of a cylindrical object; the object stood next to a cylindrical container. Next, the hand lowered the object inside the container until only the knob protruded above the rim. The container used in the *tall* event was as tall as the cylindrical portion of the object; in contrast, the container used in the *short* event was only half as tall, so that it should have been impossible for the cylindrical portion of the object to be fully lowered inside the container. Prior to the test events, the infants saw tall and short familiarization events in which the containers were rotated forward so that the infants could inspect them (see Fig. 1). The infants in the *occluder* condition saw identical familiarization and test events with one exception: The bottom and back halves of each container were removed to create a rounded occluder (see Fig. 2).

Method

Participants

Participants were 32 healthy term infants, 16 male and 16 female (range: 3 months, 20 days to 4 months, 25 days; M = 4 months, 9 days). Half of the infants were assigned to the container condition (M = 4 months, 10 days), and half to the occluder condition (M = 4 months, 8 days). Eleven additional infants were tested but eliminated, 4 because of fussiness, 3 because the primary observer could not follow the direction of their gaze, 2 because they showed a marked preference during familiarization for one of the containers or occluders, 1 because of inattentiveness, and 1 because of drowsiness.

Apparatus

The apparatus consisted of a wooden display box that was 58 cm high, 101 cm wide, and 52 cm deep and was mounted 76 cm above the room floor. The infant sat on a parent's lap and faced an opening 36 cm high and 96 cm wide in the front of the apparatus. The experimenter's hands (covered with yellow rubber gloves) were introduced into the apparatus through two windows 22.5 cm apart in the back

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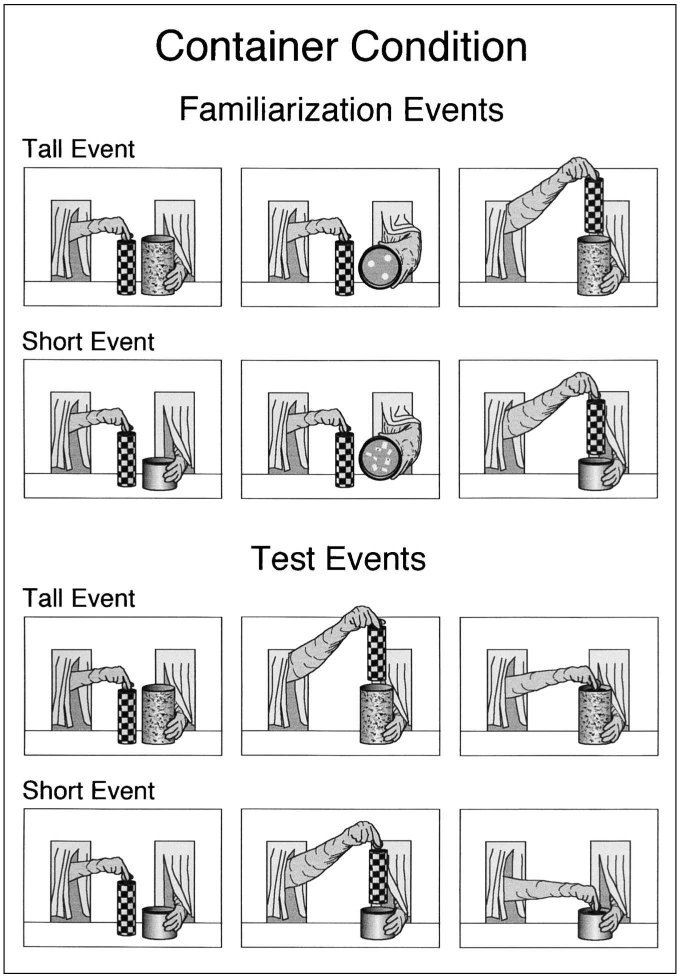

Fig. 1. Familiarization and test events in the container condition of Experiment 1. To start the familiarization events, the experimenter's left hand rotated the container toward the infant (1 s), tilted it to the right (1 s) and left (1 s), and then returned it to the apparatus floor (1 s). Next, the experimenter's right hand lifted the object vertically (1 s) and moved it to the right until it was above the container (1 s). After a 1-s pause, the object was moved back to the left (1 s) and then returned to the apparatus floor (1 s). There was another 1-s pause, and then a new event cycle was initiated. For the test events, the experimenter's right hand lifted the object vertically (1 s), moved it above the container (1 s), and then slowly lowered it until only the knob protruded above the rim (2 s). After a 1-s pause, the hand lifted the object (2 s), moved it back to the left (1 s), and then lowered it to the apparatus floor (1 s). There was another 1-s pause, and then a new event cycle was initiated. The height of the container differed in the short and tall events.

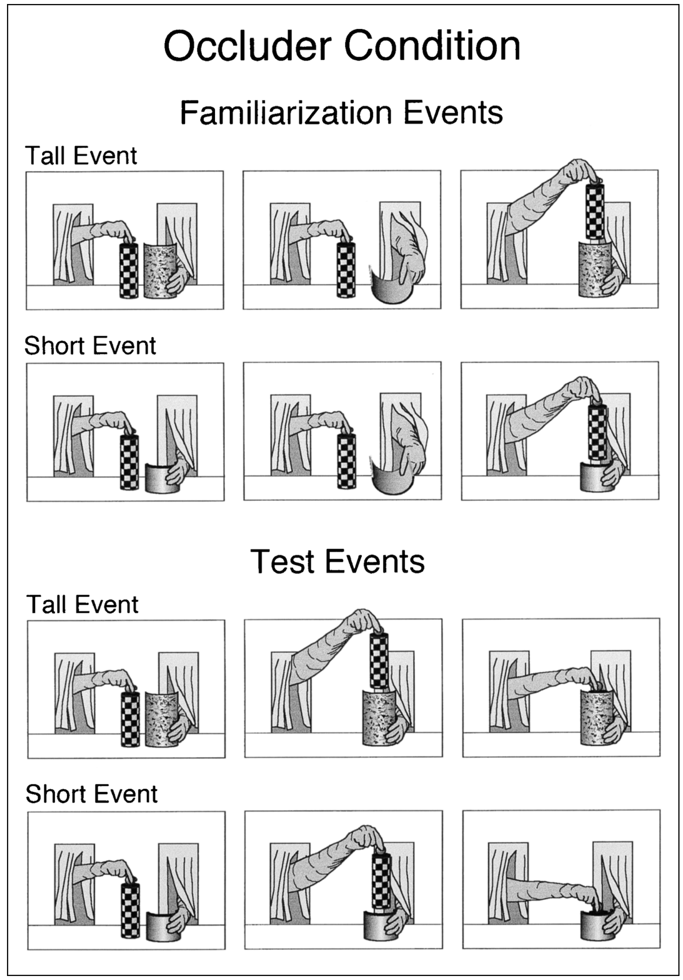

Fig. 2. Familiarization and test events in the occluder condition of Experiment 1. The events shown in the occluder condition were identical to those in the container condition (see Fig. 1) except that occluders were used in place of containers.

wall; each window was 34 cm high and 20 cm wide and was covered with a muslin fringe. Centered between the windows, 44 cm above the apparatus floor, was a peephole that was used by the experimenter to monitor his or her actions on the stimuli; a flap prevented eye contact between the infant and experimenter.

The stimuli were made of plastic pipe. The object was 16.5 cm tall and 6 cm in diameter, was closed at both ends, and was covered with black-and-white checkered contact paper; a red knob 3.5 cm in diameter was affixed to the top of the cylinder. The two containers were 12 cm in diameter and had black rims, brightly painted insides, and removable bottoms. The short container was 8.25 cm tall and was covered with green contact paper; the tall container was 17 cm tall and was covered with a gray textured contact paper. The short and tall occluders were identical to the short and tall containers, respectively, except that they had no bottom or back half. Different patterns and colors were used to decorate the short and tall containers or occluders to help the infants notice that different events were shown across trials.

During the test events, the bottoms of the containers were removed. In the short-container and -occluder test events, the object was lowered through a hidden opening 8 cm in diameter in the apparatus floor; a platform beneath the opening ensured that the object was lowered to the appropriate height. The opening was stoppered in the other events.

Procedure

In each condition, the short and tall familiarization events were shown on alternate trials for two pairs of trials; next, the short and tall test events were shown on alternate trials for three pairs of trials. Half of the infants saw the short event first during the familiarization and test trials, and half saw the tall event first.

Each infant's looking behavior was monitored by two observers who watched the infant through peepholes in curtains on either side of the apparatus. The endings of the trials were determined by the primary (typically more experienced) observer. Interobserver agreement in this and in the following experiments averaged 93% or more per trial per infant.

Each familiarization or test trial ended when the infant either (a) looked away from the event for 1 consecutive second after having looked at it for at least 10 cumulative seconds (the duration of one event cycle) or (b) looked at the event for 60 cumulative seconds without looking away for 1 consecutive second.

Preliminary analyses of the data in this and in the following experiments revealed no significant interaction involving event and sex or order; the data were therefore collapsed across sex and order in subsequent analyses.

Results and Discussion

The infants' looking times during the four familiarization trials were averaged and analyzed by means of a 2 × 2 analysis of variance (ANOVA) with condition (container or occluder) as a between-subjects factor and event (short or tall) as a within-subjects factor. No effect was significant, all Fs < 2.84, $p > .10$, suggesting that the infants in the container (short event: $M = 48.2$, $SD = 16.7$; tall event: $M = 47.4$, $SD = 16.6$) and occluder (short event: $M = 47.4$, $SD = 15.4$; tall event: $M = 52.8$, $SD = 12.7$) conditions tended to look equally at the short and tall familiarization events.

The infants' looking times during the six test trials were averaged (see Fig. 3) and analyzed in the same manner as the familiarization data. The analysis yielded a significant Condition × Event interaction, $F(1, 30) = 5.61$, $p < .025$. Planned comparisons revealed that the infants in the occluder condition looked reliably longer at the short ($M = 34.2$, $SD = 15.3$) than at the tall ($M = 26.7$, $SD = 12.8$) test event, $F(1, 30) = 7.55$, $p < .0125$, whereas those in the container condition tended to look equally at the two events, $F(1, 30) = 0.36$ (short event: $M = 30.1$, $SD = 14.1$; tall event: $M = 31.7$, $SD = 14.4$). No other effect was significant.

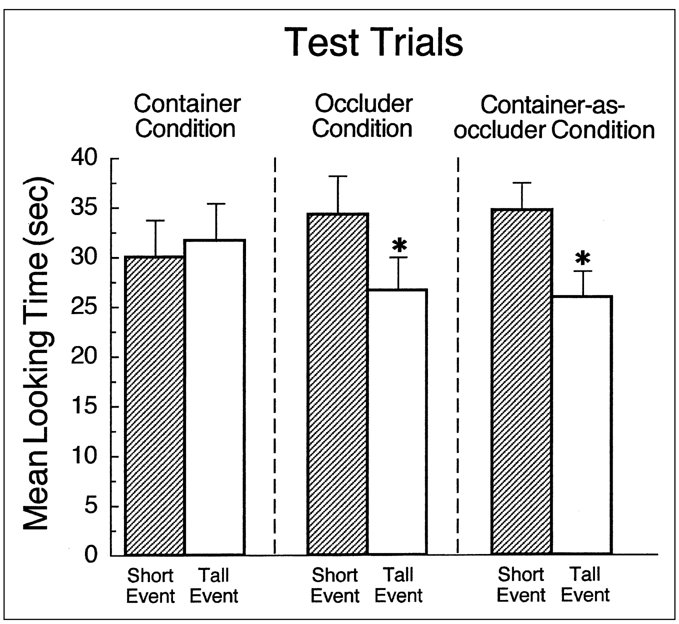

Fig. 3. Mean looking times for the short and tall test events in Experiment 1 (container and occluder conditions) and Experiment 2 (container-as-occluder condition). Significant differences in looking times between the events within each condition are marked by an asterisk ($p < .05$).

Examination of the infants' individual looking patterns revealed that 12 of the 16 infants in the occluder condition looked longer at the short than at the tall test event (cumulative binomial probability, $p < .05$), but that only 7 of the 16 infants in the container condition did so ($p > .10$).

The infants in the occluder condition detected the violation in the short test event, but those in the container condition did not. Our interpretation of these results was that 4.5-month-old infants view occlusion and containment as distinct event categories and do not generalize expectations acquired about occlusion to containment. Infants realize that the height of an object relative to that of an occluder determines whether the object can be fully or only partly hidden when behind the occluder, but they do not yet appreciate that the height of an object relative to that of a container determines whether the object can be fully or only partly hidden when inside the container.

This interpretation led to a striking prediction: Infants shown the same test events as in the container condition of Experiment 1, but with the object lowered behind rather than inside each container, should look reliably longer at the short than at the tall test event. With the containers serving as mere occluders, infants' performance should mirror that of the infants in the occluder condition of Experiment 1. Experiment 2 (container-as-occluder condition) tested this prediction (see Fig. 4).

EXPERIMENT 2

Method

Participants

Participants were 16 infants, 9 male and 7 female (range: 3 months, 24 days to 4 months, 19 days; $M = 4$ months, 7 days). Five additional infants were eliminated, 3 because of fussiness, 1 because of inattentiveness, and 1 because the primary observer could not follow the direction of the infant's gaze.

Apparatus and procedure

The apparatus and procedure used in Experiment 2 were identical to those in the container condition of Experiment 1 with two changes. In the familiarization and test trials, the container was moved forward 10 cm before the object was lifted vertically. In addition, the container was moved back 10 cm at the end of the cycle. These additions gave motion cues about the depth relationship between the object and the containers.

Results and Discussion

The infants' looking times during the four familiarization trials were averaged and analyzed by means of a one-way ANOVA with event (short or tall) as a within-subjects factor. The main effect of event was not significant, $F(1, 15) = 0.88$, suggesting that the infants tended to look equally at the short ($M = 46.8$, $SD = 11.6$) and tall ($M = 49.7$, $SD = 12.6$) familiarization events.

The infants' looking times during the six test trials were averaged (see Fig. 3) and analyzed in the same manner as the familiarization data. The analysis yielded a significant main effect of event, $F(1, 15) = 16.85$, $p < .001$, indicating that the infants looked reliably longer at

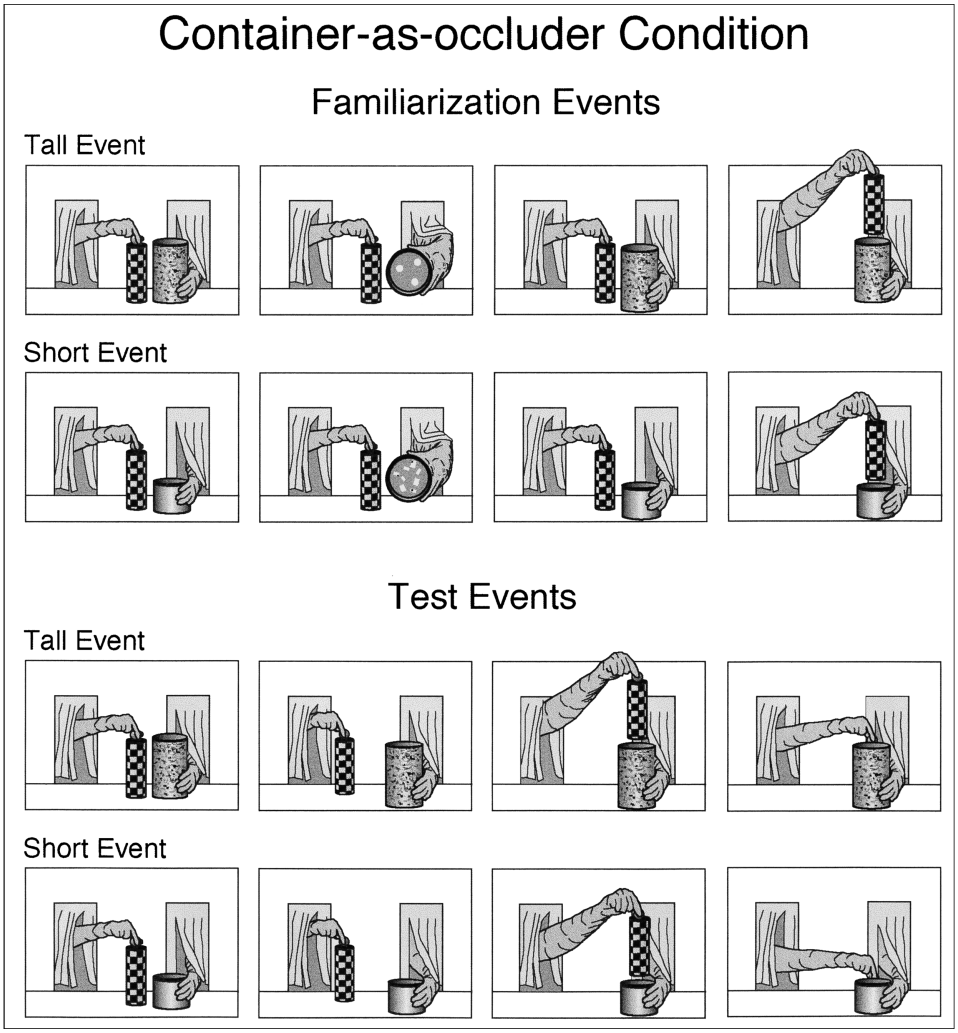

Fig. 4. Familiarization and test events in Experiment 2. The events were identical to those in the container condition of Experiment 1 (Fig. 1) with the following exceptions: (a) The container was moved forward toward the infant (1 s) before the object was lifted vertically, and (b) the container was moved back to its original position after the object was lowered to the apparatus floor (1 s). These changes made it possible for the object to be held above and behind the container (familiarization events) or to be lowered behind it (test events).

the short (M = 34.7, SD = 10.7) than at the tall (M = 26.0, SD = 10.0) test event. Fifteen of the 16 infants looked longer at the short than at the tall test event (cumulative binomial probability, $p < .002$).

An additional analysis compared the test responses of the infants in Experiment 2 and in the container condition of Experiment 1. The data were analyzed as in Experiment 1. As expected, the analysis yielded a significant Condition × Event interaction, $F(1, 30) = 6.51$, $p < .025$, confirming that the infants detected the violation in the short test event when it involved an occlusion but not a containment event.

Control experiment

An alternative interpretation of the positive results of Experiments 1 and 2 was that they reflected low-level perceptual biases in the infants' responses to the events (e.g., Bogartz, Shinskey, & Speaker, 1997; Haith & Benson, 1997). Perhaps the infants found the events in which the object was lowered behind a green occluder or container intrinsically more attractive than those in which the object was lowered behind a gray occluder or container. To examine this possibility, we tested 4.5-month-old infants in control occluder and control container-as-occluder conditions identical to those in Experiments 1 and 2, respectively, with one exception: The cylindrical portion of the object was shorter (8.25 cm tall) and so could be fully lowered behind the short and tall occluders or containers.

Participants were 16 healthy term infants, 7 male and 9 female (range: 3 months, 20 days to 4 months, 21 days; M = 4 months, 6 days). Half of the infants were assigned to the control occluder condition, and half to the control container-as-occluder condition. The infants' looking times during the six test trials were averaged and analyzed as in Experiment 1. Neither the main effect of event, $F(1, 14) = 2.20$, $p > .10$, nor the Condition × Event interaction, $F(1, 14) = 0.08$, was significant, indicating that the infants in both the control occluder (short event: M = 25.8, SD = 12.4; tall event: $M = 28.2$, $SD = 15.3$) and the control container-as-occluder (short event: $M = 26.7$, $SD = 12.6$; tall event: $M = 30.1$, $SD = 13.9$) conditions tended to look equally at the short and tall test events. Only 6 of the 16 infants (3 in each condition) looked longer at the short than at the tall event (cumulative binomial probability, $p > .10$).

In two additional analyses, the control occluder and control container-as-occluder conditions were compared with their respective experimental conditions. Each analysis involved a 2 × 2 ANOVA with condition (control or experimental) as a between-subjects factor and event (short or tall) as a within-subjects factor. Each ANOVA yielded a significant Condition × Event interaction: occluder, $F(1, 22) = 11.45$, $p < .005$; container as occluder, $F(1, 22) = 10.49$, $p < .005$. The infants in the occluder and container-as-occluder conditions thus looked reliably longer at the short than at the tall test event when these events involved the tall but not the short object.

Discussion

The infants in Experiment 2, like those in the occluder condition of Experiment 1, detected the violation in the short test event. The results of Experiment 2 thus provided converging evidence for the conclusion that 4.5-month-old infants view occlusion and containment as distinct event categories and learn separately about each category. Infants consider the height of an object relative to that of a container when the object is lowered behind but not inside the container.

It could be objected that other interpretations for the results of Experiments 1 and 2 are possible. For example, 4.5-month-old infants might possess a concept of occlusion but not containment and hence might be unable to respond appropriately to containment events. Alternatively, infants might possess concepts of both occlusion and containment, but have more difficulty reasoning about containment than occlusion events; in particular, infants might require longer exposure to containment than to occlusion events to reason about them correctly.

These alternative interpretations seem unlikely, however, given recent findings on young infants' responses to containment events (e.g., Hespos & Baillargeon, in press; Wang & Baillargeon, 2000). In a series of experiments, we found that infants as young as 2.5 months of age expect an object that has been hidden inside a container to move with it when displaced (Hespos & Baillargeon, in press). In addition, under some conditions, 4-month-old infants realize that a wide object can be lowered inside a wide but not a narrow container (Wang & Baillargeon, 2000). The infants in this last experiment received no familiarization trials, only test trials, making it unlikely that infants generally require prolonged exposure to containment events to detect violations.

EXPERIMENT 3

The results of Experiments 1 and 2 suggested that 4.5-month-old infants take into account height information when reasoning about occlusion but not containment events. At what age do infants begin to consider height information in containment events? To answer this question, we showed 5.5-, 6.5-, and 7.5-month-old infants the test events of the container condition in Experiment 1.

Method

Participants

Participants were 36 healthy term infants. There were twelve 5.5-month-olds, 5 male and 7 female (range: 4 months, 25 days to 6 months, 0 day; $M = 5$ months, 14 days); twelve 6.5-month-olds, 7 male and 5 female (range: 6 months, 8 days to 6 months, 28 days; $M = 6$ months, 22 days); and twelve 7.5-month-olds, 6 male and 6 female (range: 7 months, 3 days to 8 months, 9 days; $M = 7$ months, 15 days). Two additional infants were eliminated because they looked the maximum amount of time allowed (60 s) on every test trial.

Apparatus and procedure

The apparatus and procedure used in Experiment 3 were identical to those of the container condition in Experiment 1, with two exceptions: The infants received no familiarization trials, and they were given four rather than six test trials. Pilot data indicated that the older infants in Experiment 3 rapidly became bored with the events, and that an abbreviated procedure better maintained their interest (e.g., Baillargeon, Kotovsky, & Needham, 1995; Kotovsky & Baillargeon, 1994, 1998).

Results and Discussion

The infants' looking times during the four test trials were averaged (see Fig. 5) and analyzed by means of a 3 × 2 ANOVA with age (5.5, 6.5, or 7.5 months) as a between-subjects factor and event (short or tall) as a within-subjects factor. No effect was significant, all Fs < 2.69, $p > .08$. However, planned comparisons revealed that the 7.5-month-olds looked reliably longer at the short ($M = 44.5$, $SD = 11.2$) than at the tall ($M = 35.2$, $SD = 9.7$) test event, $F(1, 33) = 5.50$, $p < .05$; the 6.5-month-olds tended to look equally at the two events, $F(1, 33) = 0.35$ (short event: $M = 40.8$, $SD = 16.3$; tall event: $M = 38.4$, $SD = 16.7$); and so did the 5.5-month-olds, $F(1, 33) = 0.07$ (short event: $M = 28.9$, $SD = 15.3$; tall event: $M = 30.0$, $SD = 15.0$). Whereas 10 of the twelve 7.5-month-olds (cumulative binomial probability, $p < .05$) looked longer at the short than at the tall test event, only 7 of the twelve 6.5-month-olds and 7 of the twelve 5.5 month-olds did so ($p > .10$).

Additional results

The 5.5- and 6.5-month-old infants in Experiment 3 failed to detect the violation in the short test event. Would the infants have performed better if tested with the longer procedure of Experiment 1? To examine this possibility, we tested fourteen 5.5- and 6.5-month-old infants, 9 male and 5 female (range: 4 months, 25 days to 6 months, 28 days; $M = 5$ months, 20 days) using the procedure of the container condition in Experiment 1. The data were analyzed as in Experiment 1. The main effect of event was not significant, $F(1, 13) = 0.84$ (short event: $M = 23.4$, $SD = 12.6$; tall event: $M = 25.9$, $SD = 9.2$). The 5.5- and 6.5-month-old infants thus failed to detect the violation in the short test event of the container condition whether they were tested with the longer procedure of Experiment 1 or the abbreviated procedure of Experiment 3.

Control experiment

In a final control experiment, 7.5-month-old infants were shown the same test events as in Experiment 3, except that the short object described earlier was used. Participants were 12 healthy term infants, 6 male and 6 female (range: 7 months, 4 days to 7 months, 28 days; $M = 7$ months, 14 days). The infants' looking times were averaged and analyzed as in Experiment 1. The main effect of event was not significant, $F(1, 11) = 0.50$, indicating that the infants tended to look

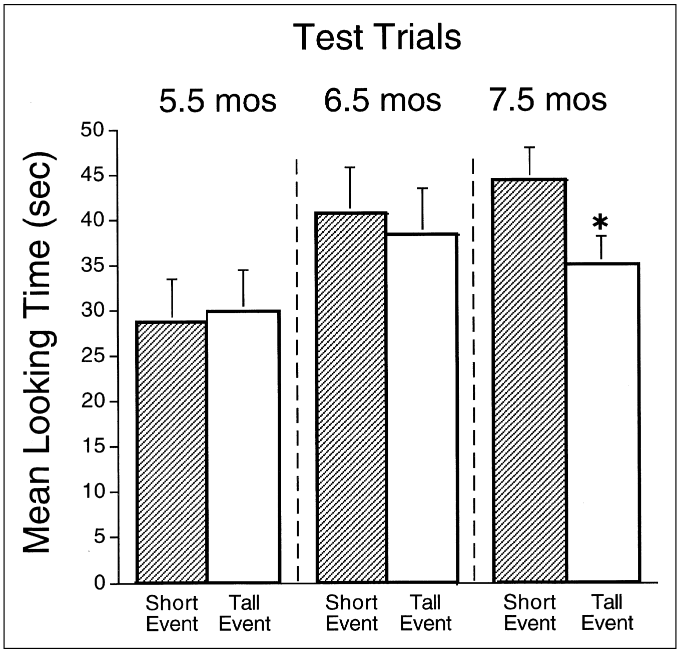

Fig. 5. Mean looking times for the short and tall test events in Experiment 3. Results are shown separately for the 5.5-, 6.5-, and 7.5-month-old infants. Significant differences in looking times between the events within each condition are marked by an asterisk ($p < .05$).

equally at the short ($M = 31.9$, $SD = 13.6$) and tall ($M = 36.0$, $SD = 14.0$) events. Only 5 of the 12 infants looked longer at the short than at the tall event (cumulative binomial probability, $p > .10$).

The infants' looking times were compared with those of the 7.5-month-old infants in Experiment 3 using a 2×2 ANOVA with condition (control or experimental) as a between-subjects factor and event (short or tall) as a within-subjects factor. The analysis yielded a significant Condition $\times$ Event interaction, $F(1, 22) = 4.30$, $p = .05$, indicating that the infants looked reliably longer at the short than at the tall test event when these events involved the tall but not the short object.

Discussion

The 7.5-month-old infants in Experiment 3 detected the violation in the short test event, but the 6.5- and 5.5-month-old infants did not. These results suggest that at about 7.5 months of age, infants begin to consider height information in containment events.

It could be objected that another interpretation is possible for the results of Experiment 3. Perhaps the 7.5-month-old infants were successful not because they had—at long last—developed expectations about height in containment events, but because they had achieved a general ability to reason about height in different physical events. However, results obtained with covering and unveiling events cast doubts on such a possibility (e.g., Baillargeon, 1993; Wang & Paterson, 2000). For example, Wang and Paterson, building on the present results, compared 9-month-old infants' ability to reason about height information in containment and in covering events (in these events, the containers were turned upside down and lowered over the object). The infants succeeded in the container condition (thereby confirming the present results), but not the cover condition. These results make it clear that at 7.5 months of age infants do not acquire a generalized ability to reason about height in different physical events.

GENERAL DISCUSSION

The present research suggests two main conclusions. First, infants view occlusion and containment as distinct event categories, and do not generalize expectations acquired about occlusion to containment. Second, more generally, infants sort physical events into distinct categories, and learn separately how each category operates.

The notion that infants acquire event-specific rather than event-general expectations is consistent with an emerging theme in the developmental literature—that infants' knowledge tends to be highly context-specific. For example, Adolph (1997) reported that infants learn to navigate steep slopes with caution in the first weeks of crawling—and again in the first weeks of walking; the knowledge that steep slopes can lead to falling is not generalized from crawling to walking but must be learned again. Similarly, Needham (2000) found that infants use featural information to segregate objects placed side by side several months before they succeed in doing the same with objects placed one on top of the other.

The present research raises many exciting questions for future research. Some of these questions concern the nature and formation of infants' event categories. For example, on what basis are categories generated? Why are occlusion and containment, in particular, viewed as distinct categories? In many cases (and contrary to the one examined here), occlusion and containment outcomes are different: For example, a wide object can be lowered behind a narrow occluder, but not inside a narrow container; and an object that has been lowered inside a container typically moves with it when displaced, but an object that has been lowered behind an occluder does not. It is plausible that these distinct clusters of interrelated causal relationships provide the bases for infants' distinct event categories (e.g., Keil, 1995; Pauen, in press).

Other questions for future research involve the acquisition of expectations within individual event categories. It is not really surprising that infants should sort physical events into distinct categories and learn separately about each category; after all, breaking down the task of learning into smaller, more manageable components is a time-honored solution to the difficulties of knowledge acquisition. But why should learning in one category precede learning in another? More particularly, why should infants learn to consider height information at about 3.5 months of age in the case of occlusion events (e.g., Baillargeon & DeVos, 1991), but only at about 7.5 months of age in the case of containment events? Our hypothesis is that this lag reflects primarily differences in the ages at which infants are exposed to appropriate evidence for learning.

In order to learn about height in occlusion or containment events, infants must (among other requirements; see Hespos & Baillargeon, in press) be able to encode the relative heights of objects and occluders or containers. Prior research (e.g., Baillargeon, 1994, 1995) suggests that infants may at first be able to encode this information only qualitatively, when the objects and occluders or containers stand side by side.[1] In the case of occlusion, infants will often see objects move behind the side edges of occluders, making it easy to compare their heights as they stand next to each other (e.g., as when a parent steps

1. When objects are held above containers, infants cannot compare their heights qualitatively—but they can compare their widths. This difference may explain why width is learned before height in containment: Infants usually have more opportunity to gather qualitative data on width than height (e.g., Aguiar & Baillargeon, 2000; Sitskoorn & Smitsman, 1995).

behind a chair, or a teapot is pushed in front of a cup). In the case of containment, however, there may be few instances in which objects are placed first next to and then inside containers; caretakers will more often insert objects directly into containers, allowing infants no opportunity to compare their heights.

These speculations suggest that infants younger than 7.5 months might be able to learn about height in containment events if exposed in the laboratory to appropriate "teaching" observations (e.g., objects of varying heights being placed next to and then inside containers). If successful, such experiments should provide strong support for the notion that age of exposure to appropriate observations crucially affects what physical expectations are learned when.[2] More generally, finding out what observations are necessary for learning should yield important insights into the mechanism responsible for infants' gradual mastery over the physical world.

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2. For teaching experiments involving support events, see Baillargeon (1998, 1999) and Baillargeon, Fisher, and DeJong (2000).