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Young Infants' Reasoning about the Physical and Spatial Properties of a Hidden Object

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The present experiments examined 7-month-old infants' ability to represent and reason about the physical and spatial properties of an occluded object. In Experiment 1, two groups of infants were tested. One group saw a screen that rotated 90° upwards and then, remaining vertical, slid backwards. The results showed that the infants expected the screen to stop sliding sooner when an object stood 10, as opposed to 25, cm behind it, suggesting that they (a) represented the location of the object behind the screen and (b) used this information to estimate at what point the screen should reach the object and stop. The other group of infants saw a screen that rotated upwards and then backwards, in the manner of a drawbridge. The results showed that the infants expected the screen to stop rotating sooner when an object 20, as opposed to 4, cm-high stood behind it, suggesting that they (a) represented the height of the object behind the screen and (b) used this information to judge at what point the screen should reach the object and stop. The infants in Experiment 2 also saw a screen that rotated upwards and then backwards. The results indicated that the infants expected the screen to stop sooner when an incompressible, as opposed to a compressible, object stood behind it (the two objects were of the same height). This finding suggested that the infants (a) represented the height and the compressibility of the object behind the screen and (b) used this information to determine at what point the screen should reach the object and whether it could continue rotating past this point (by compressing the object). The results of a control experiment supported this interpretation. Together, the results of Experiments 1 and 2 indicate that, contrary to Piaget's (1954) claims, 7-month-old infants can represent and reason about the physical and spatial properties of an occluded object. These results have implications for three areas of infancy research: object permanence, physical reasoning, and representation.

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When adults see an object occlude another object, they generally assume that (a) the occluded object continues to exist behind the occluding object and (b) the occluded object retains the physical and spatial properties it possessed prior to occlusion. Do young infants make the same assumptions? Piaget (1954) was the first to examine this question. Detailed observations of infants' reactions to occlusion events led him to conclude that infants' beliefs about occluded objects develop through six stages. During the first three stages (0 to 9 months), infants do not recognize that objects continue to exist when occluded: They assume that objects cease to exist when they cease to be visible and begin existing anew when they reappear in view. During the fourth stage (9 to 12 months), infants begin to view objects as permanent. However, this permanence is still very limited. Infants do not yet conceive of occluded objects as occupying specific locations in space and as participating in physical relations with other objects. It is not until the fifth stage (12 to 18 months) that infants become able to represent and reason about the physical and spatial properties of occluded objects. The elaboration of relations among objects, and the awareness that these relations are regulated by physical laws, are the two foremost achievements of the fifth stage. The sixth stage (18 to 24 months), which is signaled by the advent of symbolic representation, constitutes the final advance in the development of infants' beliefs about occluded objects. According to Piaget, infants are no longer limited to reasoning about properties they have directly perceived: They can now make inferences about unseen properties. For example, if shown a cloth cover with a small protuberance, they can infer that a small, as opposed to a large, object is hidden beneath the cover.

By the end of the sixth stage, the physical world of the infant is thus radically different from what it was in the beginning stages. It is a world that contains both visible and invisible objects, which exist in a unitary space and which obey the same physical laws.

REPRESENTING THE EXISTENCE OF OCCLUDED OBJECTS

Over the last two decades, Piaget's description of the development of infants' beliefs about occluded objects has been tested by many investigators (see Bremner, 1985; Harris, 1987; Schuberth, 1983; Sophian, 1984; and Wellman, Cross, & Bartsch, in press for recent reviews). A number of researchers have obtained results that contradict the claim that infants younger than 9 months of age do not believe in the continued existence of occluded objects (e.g., Baillargeon, 1986, 1987, in press; Baillargeon & Graber, 1987; Baillargeon, Spelke, & Wasserman, 1985; Hood & Willats, 1986). For example, in a series of experiments, Baillargeon (in press) habituated 3.5- and 4.5-month-old infants to a screen that rotated back and forth through a 180° arc, in the manner of a drawbridge. After habituation, a box was placed behind the screen, and the infants were shown two test events. In one (possible event), the screen rotated until it reached the occluded box; in the other (impossible event), the screen rotated through a full 180° arc, as though the box were no longer behind it. The results showed that the 4.5-month-olds, and the 3.5-month-olds who were fast habituators, looked reliably longer at the impossible than at the possible event, suggesting that they (a) believed that the box continued to exist after it was occluded by the screen and (b) expected the screen to stop when it reached the occluded box and were surprised that it failed to do so.

These results indicate that, contrary to Piaget's claims, infants represent the existence of occluded objects long before the age of 9 months. Such a finding raises the possibility that infants begin to represent the properties of occluded objects—the next stage in Piaget's sequence—before 12 months of age. A few studies have explored this possibility. They are reviewed in the next section.

REPRESENTING THE PROPERTIES OF OCCLUDED OBJECTS

The paradigm most commonly used to investigate young infants' ability to represent the properties of occluded objects has been the visual tracking paradigm devised by Bower (1974; Bower, Broughton, & Moore, 1971). In this paradigm, infants see an object move along a track whose center is occluded by a screen. On "trick" trials, the object that reappears from behind the screen is different (in size, shape, texture, and/or color) from the object that disappeared. Using this paradigm, Bower (1974) found that 5-month-old infants showed pronounced disruptions in their tracking at the sight of the novel object: they tended to look back at the screen as though in search of the original object. Later studies with infants aged 5 to 16 months (e.g., Goldberg, 1976; Gratch, 1982; Meicler & Gratch, 1980; Muller & Aslin, 1978) indicated that the incidence of disruptions in tracking was no greater when the object was changed during occlusion than when it remained the same. Nevertheless, most studies provided evidence that the infants did realize, on the trick trials, that the object that appeared from behind the screen differed from the object that had disappeared. This evidence came from a variety of measures including changes in heart rate (Goldberg, 1976), in facial expressions (Gratch, 1982; Meicler & Gratch, 1980; Parrot & Gleitman, 1987), and in postural adjustments (Gratch, 1982).

Can this evidence be taken to indicate that, when infants see an object disappear behind a screen, they assume, as adults do, that the object continues to exist and retains the properties it possessed before its occlusion? Clearly not. All that this evidence shows is that infants can discriminate between a visible object (i.e., the novel object that reappears from behind the screen) and an absent object seen a few seconds earlier (i.e., the original object that disappeared behind the screen).

The evidence from these studies is thus not essentially different from results one might obtain with a standard habituation paradigm. To make this point clearer, let us consider the following example. Infants are repeatedly shown a large red box until their looking times decline to some criterion level. A small green box is then substituted for the large red box, and the infants' looking times show a reliable increase. We could not conclude, on the basis of this finding, that the infants believed that the large red box continued to exist, retaining its same size and color, after it was removed from view. All that we could conclude is that the infants were able to discriminate between the habituation and test boxes.

Evidence that infants can distinguish objects viewed at separate points in time (an ability that is present in the first months of life; see Banks, 1983; Fagan, 1984; Mandler, 1984; Piaget, 1952; Schacter & Moscovitch, 1984) is thus not sufficient to establish what assumptions infants hold about the existence and the properties of objects when out of sight. To get at these assumptions, one needs to examine infants' ability to represent and reason about objects *during* their occlusion.

Baillargeon (1986) recently investigated 6.5- and 8-month-old infants' ability to represent and to reason about the location of an occluded object. The infants sat in front of a small screen; to the left of the screen was a long, inclined ramp. The infants were habituated to the following event: The screen was raised (so that the infants could see there was nothing behind it) and lowered, and a toy car rolled down the ramp, passed behind the screen, and exited the apparatus to the right. Following habituation, the infants saw two test events. These were identical to the habituation event except that a box was placed behind the screen. In one event (possible event), the box stood in *back* of the car's tracks; in the other (impossible event), it stood on *top* of the tracks, blocking the car's path. The results showed that the infants looked reliably longer at the impossible than at the possible event. A second experiment in which the box was placed in *front* (possible event) or on *top* (impossible event) of the car's tracks yielded the same results. Together, these results indicated that the infants (a) believed that the box continued to exist and occupied its same location after it was occluded by the screen; (b) understood that the car could not roll through the space occupied by the box; and therefore (c) were surprised to see the car reappear from behind the screen when the box stood in its path.

Baillargeon's results provide evidence that, by 6.5 to 8 months of age, infants can represent and reason about the location of an occluded object. The present experiments attempted to extend these results in two directions. First, the experiments investigated infants' ability to represent additional properties of occluded objects. They tested whether infants could represent not only the location but also the dimensions and the compressibility of an occluded object. Second, the experiments explored infants' ability to use their representations of the location, dimensions, and compressibility of an occluded object to make quantitative predictions about collisions involving this object. In her experiments, Baillargeon (1986, in press; Baillargeon et al., 1985) presented infants with a relatively simple qualitative problem: Should a moving object stop when an obstacle is hidden in its path? In the present experiments, infants were given a more difficult, quantitative problem: Should a moving object stop *at a different point* depending on the location, dimensions, and compressibility of the obstacle hidden in its path?

EXPERIMENT 1

Design

Experiment 1 tested whether 7-month-old infants are able to represent and reason about the location (sliding-screen condition) and the dimensions (rotating-screen condition) of an occluded object.

The infants assigned to the *sliding*-screen condition were habituated to a screen that rotated 90° to a vertical position, slid back 30 cm, and then repeated the same actions in reverse (see Figure 1). Following habituation, a long, thin box was placed behind the screen, and the infants saw two test events. In both events, the screen went through the same actions as before except that it slid back 25, instead of 30, cm. The only difference between the events was in the orientation and location of the box behind the screen. In one event (vertical-box event), the box stood upright 25 cm behind the screen. In the other event

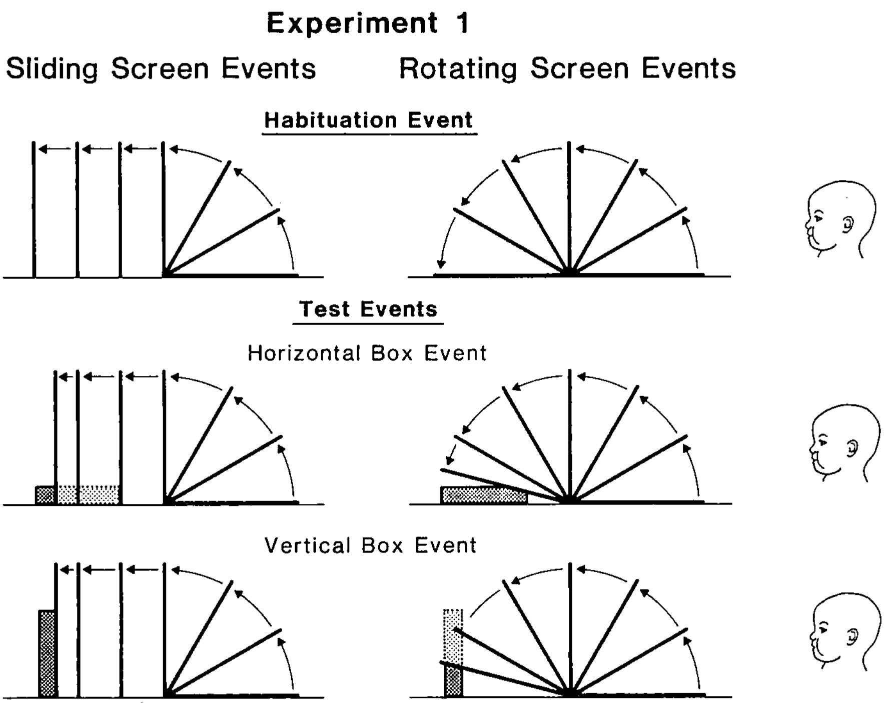

Figure 1. Schematic representation of the habituation and test events shown to the infants in the sliding and rotating screen conditions in Experiment 1

(horizontal-box event), the box lay flat 10 cm behind the screen. The 25-cm sliding motion of the screen was possible with the vertical orientation of the box (the screen stopped when it reached the box), but not with its horizontal orientation (the screen appeared to slide through the front portion of the box).

The infants assigned to the *rotating*-screen condition were habituated to a screen that rotated back and forth through a 180° arc (see Figure 1). Following habituation, the infants saw two test events. In both events, the screen rotated back and forth through a 165° arc. As before, in one event (horizontal-box event), the box lay flat behind the screen, and in the other event (vertical-box event), the box stood upright behind the screen. The 165° rotation of the screen was possible with the horizontal orientation of the box (the screen stopped when it contacted the box), but not with its vertical orientation (the screen seemed to rotate through the top portion of the box).

My reasoning was as follows. If the infants in the sliding-screen condition (a) represented the location of the box behind the screen and (b) used this information to estimate, within broad limits, the point at which the screen should reach the box and stop, then they should be surprised in the horizontal-box event when the screen continued past this point and thus seemed to slide through the space occupied by the front portion of the box. Because infants typically react to surprising or novel events with prolonged attention, the infants should look longer at the horizontal- than at the vertical-box event. On the other hand, if the infants (a) were unable to represent the location of the box behind the screen or (b) could represent this information but were unable to use it to determine at what point the screen should reach the box and stop, then they should look equally at the two test events because neither event would appear surprising.

The same reasoning applied to the infants in the rotating-screen condition: If they represented the height of the box behind the screen and used this information to estimate at what point the screen should reach the box and stop, then they should be surprised in the vertical-box event when the screen continued past this point and thus appeared to rotate through the space occupied by the top portion of the box.

In short, if the infants in the two conditions could represent and use information about the location and the height of the box behind the screen, then the infants in the sliding-screen condition should look longer at the horizontal- than at the vertical-box event, and the infants in the rotating-screen condition should show the opposite pattern of looking.

Method

Subjects. Subjects were 32 full-term infants ranging in age from 6 months, 28 days to 7 months, 24 days (M = 7 months, 13 days). An additional 8 infants were eliminated from the experiment, 4 because of fussiness or drowsiness, and

4 because of procedural errors.[1] The infants' names in this experiment, as well as in the subsequent experiments, were obtained from a file of birth announcements in a local newspaper. Parents were contacted by letters and follow-up phone calls; they were offered reimbursement for their transportation expenses but were not compensated for their participation.

Half of the infants were assigned to the sliding-screen condition, and half were assigned to the rotating-screen condition.

Apparatus. The apparatus consisted of a large, wooden box 120 cm high, 95 cm wide, and 74 cm deep. The infant faced an opening 49 cm high and 95 cm wide in the front wall of the apparatus. The interior of the apparatus was painted black and was decorated with bright, narrow stripes.

At the center of the apparatus was a silver cardboard screen 31 cm high, 28 cm wide, and 0.5 cm thick.[2] The lower edge of the screen, which was set 0.5 cm above the floor of the apparatus, was affixed to a metal rod 28.5 cm long and 1 cm in diameter. This rod was connected to a right-angle gear box 2 cm high, 3.5 cm wide, and 4 cm deep that was mounted on a horizontal slide located on the underside of the apparatus. The gear box was operated by a drive rod 62 cm long and 0.5 cm in diameter that protruded through the back wall of the apparatus. The last 8-cm section of the drive rod was bent 90°, to form a handle. By pulling or pushing this handle, an experimenter could slide the screen back and forth 30 cm; by rotating the handle, the experimenter could rotate the screen back and forth through a 180° arc.[3]

A wooden box 20 cm high, 15 cm wide, and 4 cm thick could be introduced into the apparatus through a hidden door in its back wall. This box was painted red and was decorated with dots, stars, and pushpins. The box was placed on a platform 21 cm wide and 28 cm long in the floor of the apparatus behind the screen. This platform was mounted on a vertical slide located on the underside of the apparatus. By lowering the platform, after the screen occluded the box from the infant's view, an experimenter could surreptitiously remove the box from the path of the screen. The top of the platform was covered with black cardboard. A piece of the same cardboard, 21 cm wide and 39 cm long, was mounted on a tray at the back of the apparatus. When the platform was lowered, this cardboard was

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[1] A small group of 8-month-olds were tested using the same experimental procedure. The results obtained with these infants were similar to those obtained with the 7-month-olds and so are not discussed here.

[2] Initially, a white cardboard screen 25 cm high and 25 cm wide was used. However, this screen proved somewhat difficult to operate and maintain so it was replaced by the sturdier, silver cardboard screen.

[3] To help the first experimenter move the screen at a constant, steady pace, a cardboard protractor and ruler were attached to the drive rod. In addition, the first experimenter listened through headphones to a metronome clicking once per second.

pushed forward to cover the opening in the floor of the apparatus. Black satin runners on either side of the opening made it possible to move the cardboard silently.

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 muslin-covered frames, each 183 cm high and 71 cm wide, stood at an angle on either side of the apparatus. These frames isolated the infant from the experimental room. At the end of each trial, a muslin-covered frame 65 cm high and 95 cm wide was lowered in front of the opening in the front wall of the apparatus.

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

Sliding-screen Condition

Horizontal-box-test Event. At the start of the trial, the screen lay flat against the floor of the apparatus, toward the infant. The box was clearly visible, laid flat 10 cm behind the screen. The first experimenter rotated the screen at the approximate rate of 30°/s until it had completed a 90° arc, at which point she paused for 1 s. This pause allowed the second experimenter to lower the platform and insert the black cardboard into the opening. The first experimenter then slid the screen backward (holding it vertical) at the approximate rate of 10 cm/s until it had slid 25 cm. The entire process was then repeated in reverse: the first experimenter slid the screen forward 25 cm and paused for 1 s, allowing the second experimenter to remove the cardboard and raise the platform. The first experimenter then rotated the screen down to its initial position, revealing the box standing intact in the same position as before.

Each full cycle of movement thus lasted approximately 13 s. The box remained occluded for about 11 of these 13 s: It was in view only during the first and last seconds, when the screen was raised less than 30 °. Cycles were repeated without stop until the recorder signaled that the trial had ended (see below).

Vertical-box-test Event. The vertical-box-test event was identical to the horizontal-box-test event, with one exception. Instead of lying flat 10 cm behind the screen, the box stood upright 25 cm behind the screen.

Habituation Event. The habituation event was identical to the test events, with a few exceptions. First, the box was absent. Second, the first experimenter slid the screen 30 cm instead of 25 cm, at the same approximate rate of 10 cm/s. Each cycle of movement thus lasted about 14 s.

Rotating-screen Condition

Horizontal- and Vertical-box-test Events. The horizontal- and vertical-box-test events shown to the infants in the rotating-screen condition were identical to those shown to the infants in the sliding-screen condition, with one exception.

After rotating the screen 90° and pausing for 1 s, the first experimenter, instead of sliding the screen backward, rotated it 75° toward the back wall of the apparatus, at the same rate of about 30°/s. Each cycle of movement thus lasted about 13 s, as with the test events shown to the infants in the sliding-screen condition.[4]

Habituation Event. The habituation event shown to the infants in the rotating-screen condition was identical to that shown to the infants in the sliding-screen condition, with one exception. After rotating the screen 90° and pausing for 1 s, the first experimenter, instead of sliding the screen backward, rotated it at the same approximate rate of 30°/s until it lay flat against the floor of the apparatus, toward the back wall. Thus, each cycle of movement lasted about 14 s, as with the habituation event presented to the infants in the sliding-screen condition.

The platform and black cardboard were moved in the same manner in the habituation and test events shown in the two conditions to ensure that the sounds that accompanied these movements could not contribute to differences in the infants' looking times between and within conditions.

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

The infant's looking behavior was monitored by two observers who viewed the infant through peepholes in the muslin-covered frames on either side of the apparatus. The observers could not see the experimental events, and they did not know the order in which the test events were presented. Each observer held a button box connected to an event recorder and depressed the button when the infant attended to the experimental events. The looking times of the primary observer were also registered on a set of clocks that indicated how long the infant looked and looked away during the trial. By monitoring these clocks, another assistant, the recorder, was able to signal the end of trials and to determine when the habituation criterion had been met (see below).

At the start of the experiment, each infant received 2 familiarization trials to acquaint him or her with the two possible orientations of the box. During these

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[4] Care was taken to make the test events in the two screen conditions as similar as possible. During the sliding-test events, the screen slid ⅚ of the distance it had slid during habituation (25/30 cm); during the rotating-test events, the screen rotated (after reaching the 90° position) ⅚ of the distance it had rotated during habituation (75°/90°). Further, during the horizontal-box sliding event, the screen appeared to slide through the front 15 cm of the (20-cm-long) box; during the vertical-box rotating event, the screen appeared to rotate through the top 14 cm of the (20-cm-high) box.

trials, the screen lay flat against the floor of the apparatus, with the box clearly visible behind it. In one trial, the box lay flat 10 cm behind the screen; in the other, the box stood upright 25 cm behind the screen. Each trial ended when the infant (a) looked away from the display for 2 consecutive s after having looked at it for at least 10 cumulative s or (b) looked at the display for 30 cumulative s without looking away for 2 consecutive s. Half of the infants in each screen condition saw the box in the horizontal position first, and half saw the box in the vertical position first.

Following the familiarization trials, the infant was presented with the sliding- or the rotating-screen-habituation event (depending on the condition to which the infant was assigned), using an infant-control procedure. Each habituation trial ended when the infant (a) looked away from the event for 2 consecutive s after having looked at it for at least 7 cumulative s (the duration of a half-cycle), or (b) looked at the event for 60 s. Habituation trials continued until the infant reached a criterion of a 50% or greater decrease in looking time on 3 consecutive trials, relative to the infant's looking time on the first 3 trials. If the habituation criterion was not met within 12 trials, the habituation phase was ended at that point. This occurred for 5 of the 32 infants; the other infants took an average of 7.11 trials to reach the criterion.

Following habituation, the infants in each condition saw the vertical- and the horizontal-box-test events on alternate trials until they completed three pairs of test trials. The order of presentation of the test events was patterned after that followed in the familiarization trials. At the start of each trial, the first experimenter waited to move the screen until the recorder signaled that the infant had looked at the box for 3 cumulative s. This ensured that the infant had noted the presence and the orientation of the box. Each test trial ended when the infant (a) looked away from the event for 2 consecutive s after having looked at it for at least 7 cumulative s or (b) looked at the event for 120 s.

Of the 32 infants in the experiment, 9 (5 in the sliding- and 4 in the rotating-screen condition) contributed fewer than 3 pairs of test trials to the analyses. Six infants contributed only 2 pairs, 5 because of fussiness and 1 because of recorder error. The remaining 3 infants contributed only 1 pair, because of fussiness.

Interobserver agreement for each infant was calculated on the basis of the number of seconds for which the observers agreed on the direction of the infant's gaze, out of the total number of seconds the familiarization, habituation, and test trials lasted. Agreement was calculated for 22 infants and averaged 94% per infant.

Results

Figure 2 presents the mean looking times to the horizontal- and vertical-box events by the infants in the sliding- and the rotating-screen conditions. It can be seen that the infants in the sliding-screen condition tended to look longer at the horizontal-box event, whereas the infants in the rotating-screen condition tended to look longer at the vertical-box event.

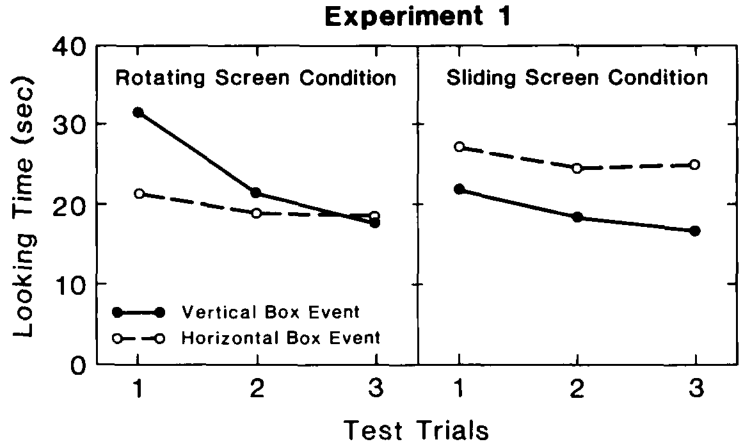

Figure 2. Looking times of the infants in the sliding- and rotating-screen conditions in Experiment 1 to the horizontal- and vertical-box test events

The infants' looking times were analyzed by means of a $2 \times 2 \times 3 \times 2$ mixed model analysis of variance with Condition (rotating or sliding screen) and Order (vertical- or horizontal-box event first) as the between-subject factors, and with Test Pair (first, second, or third pair of test trials) and Event (vertical- or horizontal-box event) as the within-subjects factors. Because the design was unbalanced, the Statistical Analysis System General Linear Model (SAS GLM) procedure (SAS Institute, 1985) was used to calculate the analysis of variance (ANOVA). As predicted, there was a significant interaction between Condition and Event, $F(1, 72) = 11.37, p < .005$. Planned comparisons showed that the infants in the sliding-screen condition looked reliably longer at the horizontal- ($M = 25.56$, $S = 15.68$) than at the vertical- ($M = 19.29$, $S = 7.89$) box event, $F(1, 72) = 7.73, p < .01$, whereas the infants in the rotating-screen condition looked reliably longer at the vertical- ($M = 24.24$, $S = 14.39$) than at the horizontal- ($M = 19.72$, $S = 11.06$) box event, $F(1, 72) = 4.02, p < .05$.

The ANOVA also yielded a significant effect of test pair, $F(2, 44) = 5.65, p < .01$, indicating that the infants looked reliably less as the experiment progressed. In addition, there was a significant effect of order, $F(1, 28) = 14.85, p < .001$, and two significant interactions involving this factor. The first was the interaction between Order and Event, $F(1, 72) = 14.71, p < .00005$. Follow-up comparisons revealed that the infants in each order condition looked reliably longer at the event they saw first (vertical-box event first, $F(1, 72) = 5.87, p < .02$; horizontal-box event first, $F(1, 72) = 9.41, p < .005$). The other significant interaction was that between Condition and Order, $F(1, 28) = 6.64, p < .05$. Follow-up comparisons indicated that the infants in the sliding-screen condition who saw the horizontal-box event first looked reliably longer overall than those who saw the vertical-box event first, $F(1, 28) = 19.22, p < .0005$, whereas the infants in the rotating condition looked equally long overall regardless of whether they saw the horizontal- or the vertical-box event first, $F(1, 28) = .58$. These types of order effects are quite common in infant studies conducted using a habituation paradigm; because they have no bearing on the theoretical issues explored in this paper, they will not be discussed further.

Discussion

The infants in the two screen conditions had reliably distinct looking patterns: The infants in the sliding-screen condition looked longer at the horizontal- than at the vertical-box event, whereas those in the rotating-screen condition looked longer at the vertical- than at the horizontal-box event. These results suggest that the infants (a) represented the location (sliding screen) and height (rotating screen) of the box behind the screen, (b) used this information to estimate at what point the screen should reach the box and stop, and therefore (c) were surprised when the screen continued to move after it reached this point. Such results suggest that, contrary to Piaget's claims, 7-month-old infants can represent and reason about some of the spatial and physical properties of occluded objects.

EXPERIMENT 2

Design

Experiment 2 examined whether 7-month-old infants are able to represent and to reason about the compressibility of an occluded object.[5]

The infants saw two test events. In both events, a white object about 15 cm high stood behind a screen that rotated back and forth through a 157° arc. The only difference between the events was in the nature of the object behind the screen. In one event (soft-object event), the object was a soft, compressible object. In the other event (hard-object event), the object was a hard, incompressible object. The 157° rotation was possible with the soft object (the screen compressed the object) but not with the hard object (the screen appeared to rotate through the space occupied by the top portion of the object).

My reasoning was as follows. If the infants (a) represented the height of the object behind the screen and used this information to judge at what point the screen should reach the object and (b) represented the compressibility of the object behind the screen and understood that the screen could compress the soft, but not the hard, object, then they should be surprised in the hard-object event when the screen continued to rotate after it reached the object. Therefore, they should look longer at the hard- than at the soft-object event. On the other hand, if the infants (a) could not represent the height and the compressibility of the

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[5] I am grateful to Bill Brewer, Susan Carey, Rochel Gelman, and Marianne Wiser who independently suggested that I examine infants' ability to reason about the compressibility of an occluded object (clearly, an idea whose time had come!). I am especially grateful to Bill Brewer, who convinced me to do it.

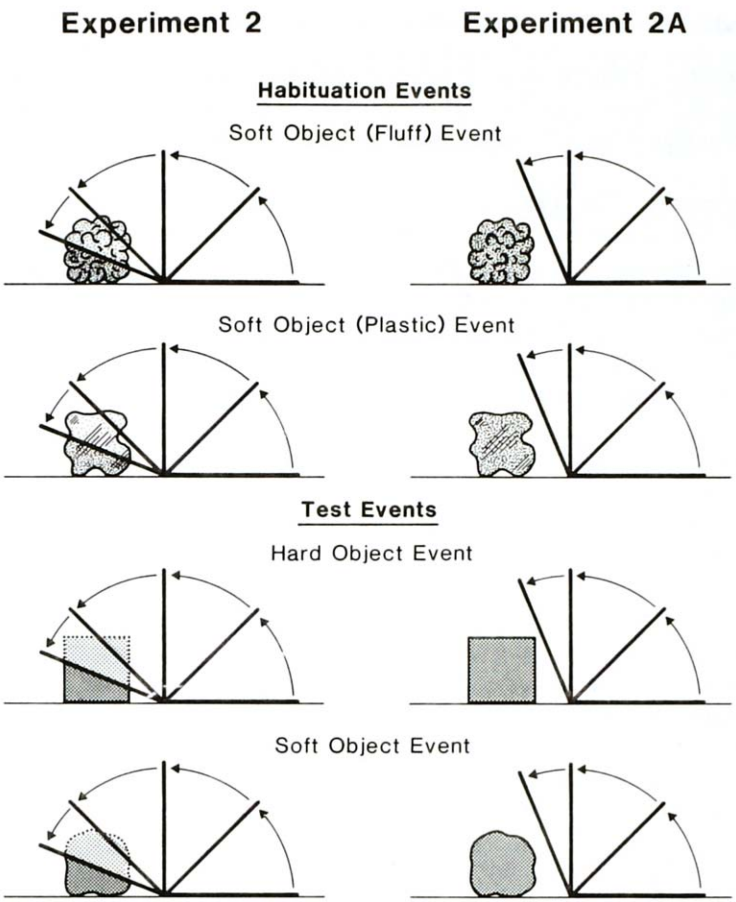

Figure 3. Schematic representation of the habituation and test events used in Experiments 2 and 2A

object behind the screen or (b) could represent this information but could not use it to judge how far the screen should rotate, then they should look equally at the two events because neither event would appear surprising.

One important concern in designing this experiment was that the infants might be as interested when the screen compressed the soft object as when it rotated through the hard object. Pilot data gave credence to this concern: Infants showed a pronounced interest in the soft-object event. To minimize the possibility of this interest masking the infants' surprise at the hard-object event, I decided to habituate the infants to the screen compressing soft objects before showing them the hard- and soft-object events. The infants saw two habituation events. These were identical to the soft-object test event except that different soft objects were used.

Method

Subjects. Subjects were 16 full-term infants ranging in age from 6 months, 12 days to 7 months, 28 days (M = 7 months, 12 days). Two additional infants were eliminated from the experiment because of fussiness.

Apparatus. The apparatus used in Experiment 2 was the same as in Experiment 1. The objects used in the habituation events were two irregular balls, one made of polyester stuffing and the other of plastic bags. The object used in the soft-object test event was an irregular ball of gauze. All three balls were about 15 cm in diameter. The object used in the hard-object test event was a wooden box 15 × 15 × 15 cm. All four objects were white and were decorated with swatches of colorful fabric, to render them more eye catching.

Events. The habituation and test events were all produced in exactly the same manner. As in Experiment 1, two experimenters worked in concert to produce the events, the first operating the screen and the second, the platform.

At the start of each trial, the screen lay flat against the floor of the apparatus, toward the infant. The soft or hard object, clearly visible, stood 8 cm behind the screen. The first experimenter rotated the screen at the rate of about 45°/s until it had completed a 90° arc, at which point she paused for 1 s (the screen was moved at a faster rate than in Experiment 1 in an attempt to render the events more interesting). During the pause, the second experimenter lowered the platform supporting the object. The first experimenter then continued to rotate the screen toward the back wall of the apparatus, at the same rate of about 45°/s, until it had completed a 67.5° arc. The first experimenter held the screen in this position for 2 s, and then the entire process was repeated in reverse. The first experimenter returned the screen to the 90° position and paused for 1 s, allowing the second experimenter to raise the platform. The first experimenter then lowered the screen to its original position on the floor of the apparatus, revealing the soft or hard object standing intact in the same location as before.

Each full cycle of movement thus lasted approximately 11 s. The object behind the screen remained occluded for about 9 of these 11 s. There was a 1-s pause between successive cycles. Cycles were repeated until the trial ended (see below).

Procedure. Prior to the beginning of the experiment, each infant was allowed to manipulate the soft and hard objects for a few seconds. The two objects used in the habituation events were presented first (balls of stuffing and plastic bags), followed by the two objects used in the test events (ball of gauze and wooden box).

Because several infants in Experiment 1 became bored or restless as the experiment progressed, an attempt was made to abbreviate the procedure. To this end, the infants received only two habituation trials, the first with the ball of stuffing and the second with the ball of plastic bags. At the start of each trial, the first experimenter waited to move the screen until the infant had looked at the object for 2 cumulative s. This ensured that the infant had noted the presence and the identity of the object. Each habituation trial ended when the infant (a) looked away from the event for 2 consecutive s after having looked at it for at least 5 cumulative s or (b) looked at the event for 45 s without looking away for 2 consecutive s.

Following these habituation trials, each infant saw the hard- and the soft-object events on alternate trials until they completed four pairs of test trials.[6] Half of the infants saw the hard object event first, and half saw the soft object event first. As before, at the start of each trial, the first experimenter waited to move the screen until the infant had looked at the object for 2 cumulative s. Each test trial ended when the infant (a) looked away from the event for 2 consecutive s after having looked at it for at least 5 cumulative s or (b) looked at the event for 60 cumulative s.

The event recorder and clocks used in Experiment 1 were replaced by a MICRO/PDP-11 computer, which now signaled the ending of the trials. Interobserver agreement was calculated for each trial on the basis of the number of seconds for which the observers agreed on the direction of the infant's gaze, out of the total number of seconds the trial lasted. Agreement was calculated for 15 of the infants and averaged 94% per trial per infant.

Three of the 16 infants in the experiment completed only three pairs of test trials, 2 because of fussiness and 1 because of drowsiness.

Results

Figure 4 presents the infants' mean looking times to the hard- and soft-object events. It can be seen that the infants tended to look longer at the hard- than at the soft-object event.

The infants' looking times were analyzed by means of a $2 \times 4 \times 2$ mixed model ANOVA, with Order (hard- or soft-object event first) as the between-subjects factor and with Test Pair (first, second, thitd, or fourth test pair) and Event (hard- or soft-object event) as the within-subjects factors. There was a significant effect of event, $F(1, 92) = 5.44$, $p < .05$, indicating that the infants looked reliably longer at the hard- ($M = 22.78$, $S = 16.90$) than at the soft- ($M = 17.53$, $S = 14.04$) object event. In addition, there was a significant effect of test pair, $F(3, 92) = 15.26$, $p = .0001$, which indicated that the infants looked reliably less as the experiment progressed.

[6] Because the infants in Experiment 2 received only 2 habituation trials and because the maximal duration of the habituation and test trials was shorter than in Experiment 1, it was decided to give the infants four pairs of test trials rather than three, as in Experiment 1.

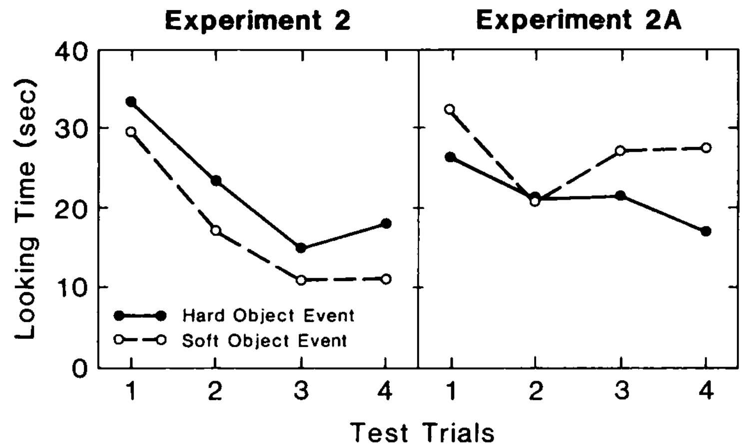

Figure 4. Looking times of the infants in Experiments 2 and 2A to the hard- and soft-object test events

Discussion

The infants in Experiment 2 looked reliably longer at the hard- than at the soft-object event. This result suggests that the infants (a) represented the height of the object behind the screen and used this information to estimate at what point the screen should contact the object; (b) represented the compressibility of the object behind the screen and understood that the screen could compress the soft, but not the hard, object; and therefore (c) were surprised when the screen continued to rotate after it reached the hard object.

However, there are other possible interpretations for the results of Experiment 2. It could be that the infants looked longer at the hard-object event because they found the hard object intrinsically more interesting than the soft object. Alternatively, the infants could have looked longer at the hard-object event because they perceived that the hard object belonged to a different "category" (e.g., incompressible objects, square objects, objects with regular contours) than the soft objects used in the habituation events and in the soft-object event (e.g., compressible objects, rounded objects, objects with irregular contours).

To check these alternative interpretations, I ran a control experiment that was identical to Experiment 2 with one exception. Instead of rotating through a 157° arc, the screen rotated through a shorter, 112° arc: it stopped just before it reached the hard or soft object behind it (see Figure 3). If the infants in Experiment 2 looked longer at the hard-object event because they found the hard object more interesting than the soft object or because they thought that the hard object belonged to a different category than the soft objects, then the infants in Experiment 2A should also look longer at the hard-object event. On the other hand, if the infants in Experiment 2 looked longer at the hard-object event because they were surprised when the screen continued to rotate after it reached the incompressible hard object, then the infants in Experiment 2A should look equally at the hard- and soft-object events because neither event would appear surprising.

Experiment 2A

Subjects. Subjects were 16 full-term infants ranging in age from 6 months, 6 days to 8 months, 0 days (M = 7 months, 5 days). One additional infant was eliminated from the experiment because of fussiness.

Apparatus, Events, and Procedure. The apparatus, events, and procedure used in this experiment were the same as in Experiment 2 with one exception: During the habituation and test events, the screen was rotated 112° instead of 157°. After rotating the screen 90° and pausing for 1 s (to allow the second experimenter to lower the platform), the first experimenter rotated the screen 22.5° toward the back wall of the apparatus, taking 0.5 s to complete the movement. The first experimenter held the screen in this position for 2 s, and then the entire process was repeated in reverse. Each full cycle of movement thus lasted approximately 9 s, and the object behind the screen remained occluded for about 7 of these 9 s.

Two of the 16 infants in the experiment failed to complete 4 pairs of test trials: They completed only 3 pairs, due to fussiness. Interobserver agreement averaged 93% per trial per infant.

Results

Figure 4 presents the mean looking times to the hard- and soft-object events. It can be seen that, in contrast to the infants in Experiment 2, the infants in Experiment 2A tended to look longer at the soft- than at the hard-object event.

The infants' looking times were analyzed as in Experiment 2. The main effect of event was marginally significant, $F(1, 92) = 3.21$, $p < .08$, suggesting that the infants tended to prefer the soft- ($M = 26.91$, $S = 17.90$) over the hard- ($M = 21.60$, $S = 17.48$) object event. No other effects were significant, all Fs < 1.86, $p > .14$.

One final analysis of variance was conducted comparing the performances of the infants in Experiments 2 and 2A. This analysis was a $2 \times 2 \times 3 \times 2$ mixed model ANOVA, with Condition (157° or 122 ° rotation) and Order (hard- or soft-object event first) as the between-subjects factors, and with Test Pair (first, second, third, or fourth test pair) and Event (hard- or soft-object event) as the within-subjects factors. As expected, there was a significant interaction between Condition and Event, $F(1, 184) = 7.95$, $p = .005$, showing that the infants in Experiments 2 and 2A had reliably different patterns of looking at the hard- and soft-object events. The only other significant effect was that of test pair, $F(3, 184) = 10.50$, $p = .0001$, indicating that the infants looked reliably less as the experiment progressed.

Discussion

The infants in Experiment 2A showed a weak, marginally significant preference for the soft- over the hard-object event. This result provides strong evidence that the infants in Experiment 2 looked longer at the hard-object event, not because they found the hard object more interesting than the soft object or because they recognized that the hard object belonged to a different category than the three soft objects shown in the habituation and test events, but because they were surprised when the screen continued to rotate after it reached the incompressible hard object. Together, the results of Experiments 2 and 2A indicate that the infants (a) represented the height and the compressibility of the object behind the screen and (b) used this information to estimate how far the screen could rotate.[7]

GENERAL DISCUSSION

The infants in the sliding-screen condition in Experiment 1 looked longer at the horizontal- than at the vertical-box event, suggesting that (a) they represented the location of the box behind the screen and (b) they used this information to estimate at what point the screen should reach the box and stop. The infants in the rotating-screen condition in Experiment 1 looked longer at the vertical- than at the horizontal-box event, indicating that (a) they represented the height of the box behind the screen, and (b) they used this information to judge at what point the screen should contact the box and stop. Finally, the infants in Experiment 2 looked longer at the hard- than at the soft-object event, suggesting that (a) they represented the height as well as the compressibility of the object behind the

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[7] The results of Experiments 2 and 2A also help rule out a possible, though unlikely, interpretation for the results of Experiment 1. It might be argued that the infants in the sliding (rotating) condition in Experiment 1 looked longer at the horizontal-(vertical) box event because they were surprised to see the space occupied by the box alternately full (when the box was visible at the beginning and end of the event) and empty (when the screen had moved through the space occupied by the occluded box). The infants might not have realized that the box continued to exist and retained its properties behind the screen. They might simply have been intrigued by the fact that the same spatial location was filled with the box one moment and empty the next moment. In the sliding vertical-box event and the rotating horizontal-box event, the location filled with the box, when visible, was never empty.

As indicated earlier, the results of Experiments 2 and 2A argue against this interpretation of the results of Experiment 1. The infants in Experiment 2 looked longer at the hard- than at the soft-object event, despite the fact that in both events the space occupied by the object was alternatively full (when the object was visible at the beginning and end of the event) and empty (when the screen either compressed or moved through the object). If the infants in Experiment 1 had been responding merely to empty/full changes in the location occupied by the box, one would have expected the infants in Experiment 2 to have done the same and hence to have looked equally at the hard- and soft-object events. The fact that they did not provides evidence that the infants in Experiment 1 looked longer at the impossible events they were shown because they were surprised to see the screen move through space occupied by the occluded box.

screen, and (b) they used this information to determine at what point the screen should reach the object and whether the screen could continue rotating past this point.

These results have implications for three areas of research in infancy: object permanence, physical reasoning, and representation. With respect to object permanence, the results show that, contrary to Piaget's (1954) claim, 7-month-old infants recognize that objects retain their physical and spatial properties when occluded. This finding, together with the previous finding that 3.5-month-old infants understand that objects continue to exist when occluded (Baillargeon, in press), call into question Piaget's description of the development of object permanence. The findings are consistent with two alternative claims. The first, weaker claim is that Piaget was correct in maintaining that infants' beliefs about occluded objects develop through a sequence of stages, but underestimated by at least 5 months the rate at which infants proceed through these stages. The second, more radical claim is that Piaget was mistaken in positing a stage sequence. In this view, infants realize early in infancy that objects continue to exist and retain their properties when occluded. What develops over time is not their conception of occluded objects but their ability to represent and to use information about occluded objects. It seems plausible that (a) as infants' representational and mnemonic capacities develop, they represent occluded objects with greater detail and for longer time periods, and (b) as infants' physical knowledge expands, they become better at anticipating the outcomes of physical events involving occluded (as well as visible) objects. Further research is needed to decide which of these two claims is correct. Evidence that very young infants represent and reason about some of the properties of occluded objects would clearly argue in favor of the second, more radical claim (see Baillargeon, 1987; Baillargeon & Graber, 1987).

With respect to physical reasoning, the present results indicate that, by 7 months of age, infants are able not only to represent the properties of occluded objects, but also to use these representations to reason about simple physical events involving the objects. Further, infants are able to reason not only qualitatively, but also quantitatively about events. The infants in the experiments not only expected the screen to stop, during the test events, but also had expectations as to *where* the screen should stop. To form these expectations, the infants had to carry out two tasks. First, they had to analyze the screen's motion to determine which property of the object (e.g., its height) they should attend to. Second, they had to use this information to estimate the screen's probable stopping point.

The results of the present experiments are not sufficient to draw conclusions about the accuracy of infants' quantitative reasoning abilities. All that the results tell us is that, at 7 months of age, infants expect that (a) a sliding screen will stop sooner when an object is placed 10, as opposed to 25, cm behind it; (b) a rotating screen will stop sooner when a 20-cm, as opposed to a 4-cm, object is placed behind it; and (c) a rotating screen will stop sooner when a 15-cm incompressible, as opposed to compressible, object is placed behind it. Further research is needed to establish how well infants perform when presented with more difficult discriminations than those used here. For example, do infants expect a rotating screen to stop sooner when an 8-cm, as opposed to a 4-cm, box is placed behind it? Answers to these questions will inform us about the precision and accuracy of both infants' representations and quantitative reasoning abilities.

As mentioned earlier, the results of the present experiments also have implications for research on infants' representational abilities. According to Piaget (1952) and, indeed, most developmental psychologists (see Mandler, 1983, 1984, for a critique of this view), infants less than 18 months of age do not have a symbolic representational system. All that they have are sensorimotor schemes: perceptual and motor procedures for recognizing objects and for acting upon them. Without external support, infants are incapable of evoking absent objects; and even with support, their performance is still very limited: "At best, after about a year of life, [infants are] said to be capable of 'prevision', in which the early portion of a familiar sequence gives rise to a kind of imageless (contentless) anticipation of something further" (Mandler, 1984, p. 76).

Can the results of the present studies be accounted for in terms of the limited representational abilities assumed to be available to young infants? The answer is unclear. One could argue that the infants in the experiments were able to keep the object in mind after it was occluded by the screen because the screen itself provided external support for the object. Further, one could propose that the infants were able to anticipate the intersection of the screen and the object because of their emerging "prevision" ability. However, several rejoinders could be offered to these arguments. The first is that the infants in the experiments remembered not only the presence, but also the properties of the object behind the screen, and they kept track of these as they changed from trial to trial. It is difficult to imagine how the screen, which remained unchanged, could have helped the infants keep in mind the identity (Experiment 2) or the orientation (Experiment 1) of the object on each trial. Second, it is doubtful whether an appeal to Piaget's notion of prevision can carry explanatory weight, for two reasons. One is that the infants' anticipations were far more specific than the imageless, contentless anticipations described by Piaget. During the test trials, the infants did not have merely a vague expectation that the screen would stop: They expected it to stop at different points depending on the location, the height, and the compressibility of the object placed behind it. The other reason is that prevision is typically invoked for anticipations observed in the context of familiar scenes and routines. The infants were undoubtedly familiar, at an abstract level, with the type of event they were shown (the intersection of a moving object with a stationary obstacle). But, at a more specific level, it is unlikely that they had often been exposed to rotating or sliding screens. Therefore, the expectations the infants revealed could not have been based on past observations; they had to be derived during the experiments themselves. Such expectations are not easily reconciled with the conditioned anticipations of prevision.

The foregoing speculations suggest that, by 7 months of age, infants may possess more sophisticated representational abilities than has traditionally been assumed (cf. Mandler, 1984, and Moscovitch, 1985, for similar suggestions). For instance, it might be that young infants possess some primitive form of visual imagery, which they can rely on to anticipate the outcome of simple physical events. In this context, it is interesting to consider the charming anecdote in which Piaget (1952) described how his daughter Jacqueline, at the age of 20 months, made use of a visual image to solve a simple physical problem. Jacqueline came to a closed door with a blade of grass in each hand. She put the blade she held in her right hand on the floor at the foot of the door and seized the doorknob. She then stopped, picked up the blade, and moved it out of the path of the door, before going back to open the door. According to Piaget, Jacqueline recognized that, in pulling the door, she would crush her blade of grass so she moved it out of harm's way. Piaget perceived Jacqueline's action as being "very characteristic of the intelligent acts founded upon [symbolic] representation. . ." (p. 339).

There are important similarities between the performance of the infants in Experiments 1 and 2 and that of Jacqueline in Piaget's anecdote. Both the infants and Jacqueline were faced with a problem about the intersection of a moving object and a stationary obstacle (moving screen and box for the infants; moving door and blade of grass for Jacqueline). Both appreciated that the two objects would intersect, and both were able to judge approximately where the objects would intersect. It is possible that, in reasoning about the intersection of the objects, the infants were making use of visual images which, although primitive, were nevertheless the forerunners of the representations formed by Jacqueline. Reasearch is needed to specify the exact nature of young infants' representations and the relation of these representations to the symbolic and conceptual representations of young children.

In conclusion, the results of the present experiments suggest that, by 7 months of age, infants represent not only the existence but also the physical and spatial characteristics of hidden objects. Further, they use these representations to reason about simple events involving the objects. In general, these findings suggest that infants' knowledge about the physical world and ability to understand and anticipate events in that world are far more sophisticated than was hitherto suspected.

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