Cognitive Development, 11, 3–17 (1996)

Tracking and Anticipation of Invisible Spatial Transformations by 4- to 8-Month-Old Infants

Philippe Rochat
Susan J. Hespos
Emory University

The ability of 4- to 8-month-old infants to track and anticipate the final orientation of an object following different invisible spatial transformations was tested. A violation-of-expectation method was used to assess infants' reaction to possible and impossible outcomes of an object's orientation after it translated or rotated behind an occluder. Results of a first experiment show that at all ages infants tend to look significantly longer at an impossible orientation outcome following invisible transformations. These results suggest that from 4 months of age, infants have the ability to detect orientation-specific information about an object undergoing linear or curvilinear invisible spatial transformations. A second experiment controlling for perceptual cues that infants might have used in the first experiment to track the object orientation replicates the results with a new sample of 4- and 6-month-old infants. Finally, a control experiment involving no motion yielded negative results, providing further support that infants as young as 4 months old use motion information to mentally track invisible spatial transformations. The results obtained in the rotation condition of both experiments are tentatively interpreted as providing first evidence of some rudiments of mental rotation in infancy.

A general principle established by recent progress in infancy research is that from approximately 4 months of age, out of sight does not mean out of mind (Baillargeon, 1993). This principle contrasts sharply with the view proposed by Piaget (1954) in his seminal work on the origins of intelligence. Based on observations pertaining to manual search tasks, Piaget proposed that up to approximately 9 months, infants do not endow objects with permanence. In particular, when infants younger than 9 months witness the occlusion of an

---

The authors wish to acknowledge Erin Ebert, Russell Goodman, Mark Plotkin, and Sarah Schwartz for helping in the data collection and analysis. They express their appreciation to the parents and infants who participated in the study, and to Michael Tomasello, Ulric Neisser, Rachel Morgan, and Paul Scott for their comments. The research was supported in part by grant No. MH50385-01 from the National Institute of Mental Health and two Summer Research Grant awards (1992 and 1994) from Emory University awarded to Philippe Rochat and a CIBA predoctoral grant to Susan J. Hespos.

Correspondence and requests for reprints should be sent to Philippe Rochat, Department of Psychology, Emory University, Atlanta, GA 30322.

Manuscript received December 16, 1994; revision accepted August 14, 1995

attractive object, they stop searching for it and do not show any systematic attempts to remove the occluder in order to fetch it. Piaget concluded that young infants behave as if out of sight means out of mind. Recent research demonstrates that infants younger than 9 months may continue to be aware of objects that are momentarily out of sight. Six-month-old infants reach for an object they hear sounding in the dark, preparing their reach as a function of the anticipated size of the object (Clifton, Rochat, Litovsky, & Perris, 1991). Four- to 5-month-old infants perceive the unity of a partly occluded object (Kellman & Spelke, 1983), and understand that hidden objects occupy space and are substantial (Baillargeon, Spelke, & Wasserman, 1985). In their landmark experiment, Baillargeon et al. (1985) observed that 5-month-olds look longer at the impossible outcome of an event in which a visible screen rotates through the space occupied by a solid object, hidden behind the screen. They look significantly longer at this outcome compared to a possible one in which the rotating screen stops when it reaches the hidden object. In subsequent experiments, Baillargeon (1993) showed that young infants detect invariants relevant to the size, substance, and location of hidden objects. From 4 months, infants appear to represent hidden objects in terms of their location and particular physical characteristics. Using a similar experimental paradigm, Spelke, Breinlinger, Macomber, and Jacobson (1992) demonstrated that infants as young as 10 weeks differentiate among particular outcomes of partly occluded transformations. They observe that infants tend to look longer at outcomes violating basic rules such as the object's continuity and solidity. Overall, there is now good evidence that long before 9 months infants show rudiments of object permanence and have basic knowledge about objects that are temporarily out of sight.

However, this ability continues to develop through the course of the first year. Baillargeon (1993, 1995) suggested that the mental representation of hidden objects develops from being "all-or-none" reasoning to nuanced reasoning about specific variables. Even though 4-month-olds are aware that something is hidden behind the occluder, they become progressively more specific about their representation of hidden objects' physical characteristics (Baillargeon, 1993, 1995). Spelke et al. (1992) reported that 4-month-old infants do not react significantly to an event violating the principles of gravity and inertia. Xu (1993) reported that it is not until 10 months that infants start to show sensitivity to objects' physical identity.

Beyond the demonstration that out of sight does not mean out of mind for infants younger than 8 months, questions remain regarding the nature of early mental representation. In their work on the development of mental imagery in children, Piaget and Inhelder (1971) provided a useful classification of mental imagery, making a basic distinction between *static* and *kinetic* mental images. According to Piaget and Inhelder, static images correspond to the mental representation of an object, independent of any transformation. Kinetic images, on the other hand, correspond to the mental representation of the object's transformation per se. Based on a series of studies evaluating children's drawings, Piaget and collaborators suggested that static images develop first. In particular, it is only by 7 to 8 years of age that children can describe and interpret invisible transformations beyond the mere static mental representation of the start and end points of a transformation. Piaget concluded that this development corresponds to children's growing ability to manipulate mental images. An analogous progression was suggested by Piaget (1954) regarding the development of object permanence. In the context of manual search tasks, Piaget observed that infants first can recover a hidden object at a single location (Stage 4 of the sensorimotor period) and are eventually capable of representing its invisible displacements in a final stage achieved by 18 months. Using looking as a response, it has been shown that the static location and continuing existence of hidden objects is represented at an earlier age than Piaget suggested (Baillargeon, 1993). However, no research has tested the possibility of young infants' mental representation of invisible transformations in the context of preferential looking paradigms.

The general aim of the present research is to specify further the nature of early mental representation. Using a looking paradigm, the specific goal is to investigate whether infants 8 months old and younger are capable of representing invisible transformations. In the context of Piaget and Inhelder's (1971) distinction, the general question guiding the research is whether young infants are capable of generating kinetic mental images. This question is addressed by investigating the ability of young infants to track invisible changes in orientation of an object that is either translating or rotating behind an occluder. Are infants younger than 8 months capable of mentally tracking invisible spatial transformations of an object and discriminating among possible and impossible outcomes of such transformations?

EXPERIMENT 1

Method

Participants. Thirty full-term healthy infants (19 boys and 11 girls) participated in the experiment. They were divided into three groups: ten 4-month-olds (*M* = 4 months, 18 days; range = 4 months, 10 days to 4 months, 27 days); ten 6-month-olds (*M* = 6 months, 15 days; range 5 months, 28 days to 6 months, 28 days); and ten 8-month-olds (*M* = 8 months, 14 days; range 8 months, 1 day to 9 months 8 days). Eight additional babies were tested but not included in the final sample due to fussiness (7) or experimenter's error (1).

Apparatus. Infants were placed 2 m from the front of a stage, 115 cm high, 120 cm wide, and 36 cm deep. The walls and floor of the stage were covered with black fabric. The lower backdrop consisted of a trap door made of the same material giving the experimenter access to the object on stage. On the front edge of the stage was a white opaque occluder 52 cm wide and 36 cm tall made of Styrofoam board. From behind the stage, via a system of pulleys, the occluder could be raised to occlude the lower portion of the stage or lowered to reveal it. When the occluder was raised, the experimenter could surreptitiously change the orientation of the object from behind the occluder, through the trap door.

The room was lit by a clamp lamp located behind and 1 m above the infant's head. The stage was illuminated by two 60-watt lamps clamped to the top left and right front corners. The lamps were concealed from the infant's view by a black curtain hanging from the ceiling (120 cm × 40 cm). Both room and stage lighting were controlled by a dimmer switch accessible to the experimenter from behind the stage. Two cameras provided video recording of the testing sessions; one was placed behind the stage, and the other was placed above and behind the infant. The lens of the camera behind the stage was placed against a 5-cm diameter hole in the black backdrop at the infant's eye height. When the screen was lowered, this camera provided a view of the infants' face as they were looking at the display. The other camera provided a view of the object on stage as seen from the infant's point of view. Images from both cameras appeared on either side of a split-screen (Pelco model US100DT). In addition, a digital clock (Video Timer VTG22) was superimposed on the image. The split-screen image was both recorded and monitored online on a small TV monitor behind the stage permitting the experimenter to observe the infant throughout testing and to monitor when the infant looked away from the display for longer than 2 s (see the next section on procedure).

The object was made of two pieces of hard foam blocks glued together. These pieces were a bright red rectangular shape 16 cm tall, 8 cm wide, and 4 cm deep with a semicircle (8 cm in diameter) cut out of the long side, and a bright yellow rectangular solid 16 cm tall, 4 cm wide, and 4 cm deep (see Figure 1). The entire object was 24 cm long. Two vertical strips of clear Plexiglas were affixed to the center backdrop of the stage providing a track for the moving object in the translation condition (see the next section on procedure). The Plexiglas strips were 4 cm wide and 80 cm tall with a 1-cm space between them. Two thin pieces of wood (popsicle sticks) glued to the back of the object provided a guide once inserted in the Plexiglas track.

A radial arm made of a black round metal rod (.5 cm in diameter painted the same black as the stage's cloth backdrop) was used to move the object in the rotation condition (see the next section on procedure). The rod protruded from the backdrop by 6 cm, and extended parallel to the back-

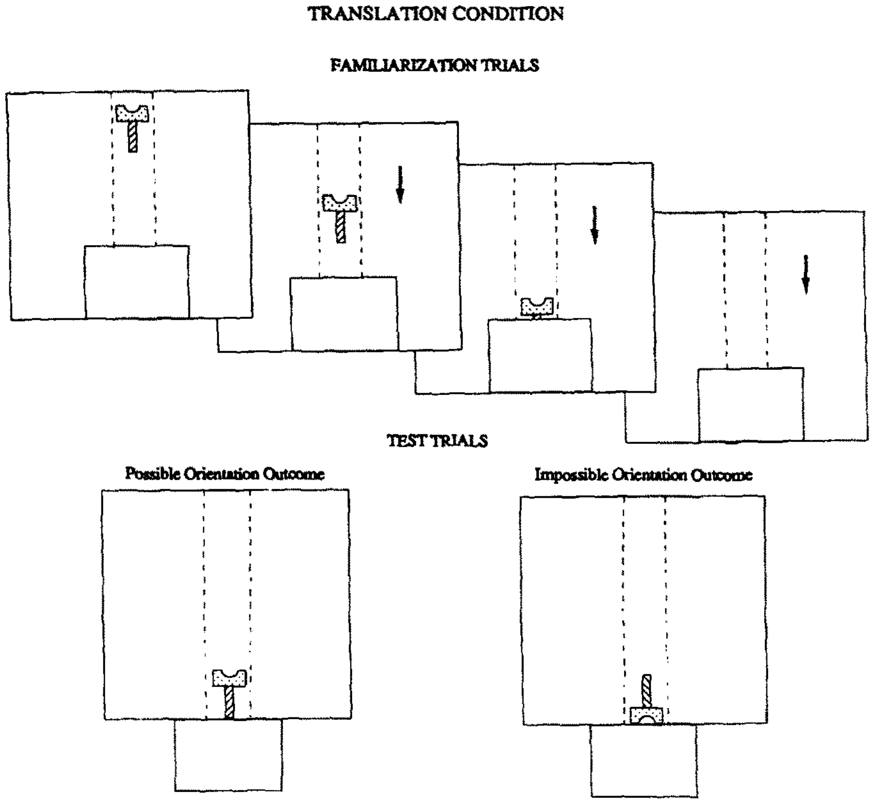

Figure 1a. Diagram depicting the translation condition with possible versus impossible orientation outcomes presented during test trials of Experiment 1. Dotted lines represent the transparent vertical Plexiglas track.

drop to form a 40-cm radial arm. The experimenter controlled the radial movement of the arm from behind the stage. When moved, the extremity of the arm where the object was attached described a 180° arc from 12 to 6 o'clock.

Procedure. During the experiment, the infant sat on the parent's lap facing the stage. The parent was asked not to interact with the infant, holding him or her gently by the hips. Each infant was tested in succession in two conditions: a translation and a rotation (see later descriptions). In the translation condition, infants were shown an object falling vertically along a track, disappearing behind an occluder (see Figure 1a). In the rotation condition, infants were shown an object attached to the extremity of an arm rotating through a 180° arc, from 12 to 6 o'clock and disappearing behind an occluder at 4 o'clock. Thus, the object was visible for two thirds of the

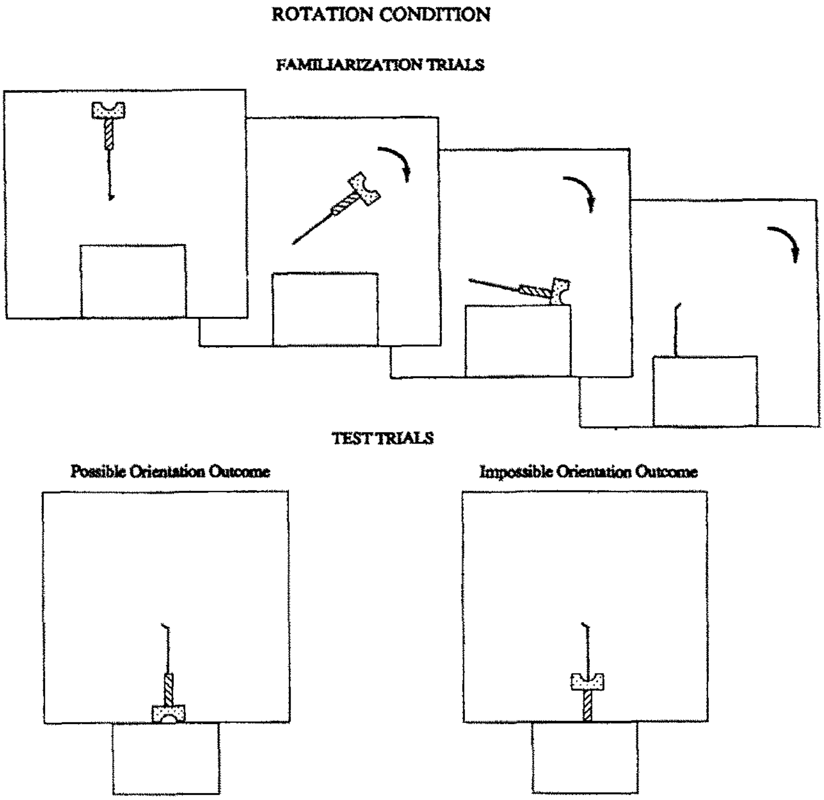

Figure 1b. Diagram depicting the rotation condition with possible versus impossible orientation outcomes presented during test trials of Experiment 1. Note that the radial arm represented on the diagram and supporting the object was of the same color as the backdrop.

rotation event (the same as in the translation event). Note that the center portion of the radial arm was always visible to provide information about the object motion behind the occluder. However, the rotating arm was painted black and only the object was colorful and perceptually prominent (see Figure 1b).

In the translation condition, the infant was shown six successive familiarization trials with the object disappearing behind the raised occluder. At the beginning of each trial, the object was presented at the top of the vertical track, held by the experimenter who waved the object to attract the infant's visual attention. Once the infant had fixated the object for approximately 2 s, the experimenter let the object drop down the vertical track behind the raised occluder. When the object hit the stage, it made a single, distinct audible sound. This procedure was repeated six times. The rationale for these six familiarization trials was to acquaint the infant with the motion of the object, with its final orientation being occluded. Following familiarization, infants were presented with six successive test trials. Again, the object was dropped down the vertical track, disappearing behind the occluder. Following the vertical translation, the screen was lowered, revealing the object in either a possible or impossible orientation outcome. The possible orientation corresponded to the starting orientation, and the impossible orientation corresponded to a 180° inversion of the starting orientation (see Figure 1b). On trials with the impossible orientation, prior to lowering the screen, the experimenter surreptitiously removed the object from the track and flipped it by 180° through the trap door behind the occluder (see previous description). Note that in the possible condition, to equate time and noise, the experimenter performed the exact same maneuver except for rotating the object. From the moment the screen was lowered, looking time at the revealed object was measured based on a close-up video recording of the infant's face. When the infant looked away from the object for 2 consecutive seconds, the screen was raised and a new test trial began. The occlusion time, measured from the time the object disappeared behind the screen until it was revealed was consistently 4 s long. The intratrial interval was always 3 s. During the six test trials, the orientation alternated between possible and impossible outcomes.

In the rotation condition, the same familiarization and test procedure was used, except that the spatial transformation was different (see Figure 1b). The only procedural difference was that between trials, the lights in the room were turned off so the experimenter could rotate the object back to the starting position (12 o'clock) without the infant witnessing it. Note that in the translation condition, the object was placed back at the starting position from behind the backdrop, thus not requiring a black out.

The order of condition (i.e., translation first or rotation first), starting orientation (i.e., Y-shaped object or inverted Y), and test order (i.e., possible outcome first or impossible outcome first) were counterbalanced among infants of each age group.

Scoring. Two independent coders analyzed the video recordings of infants' looking during the test trials, from the moment the screen was lowered until the infant looked away for 2 s. Coding was based on an online viewing procedure of the video recording. While viewing the video recording, coders recorded infant's looking at the display by pressing a button that activated one channel of a computerized event recorder. During scoring, an opaque sheet covered the portion of the split image on the TV monitor depicting the event on stage. Coders were blind to what display the infant was presented with and whether they were looking at a possible or impossible orientation. From this coding, looking time at the display was measured. Based on the methodology established by researchers using the same experimental paradigm, looking time was operationally defined as the first look at the display that was longer than 1 s, ending when the infant looked away from the display for longer than 2 s. This operational definition is directly borrowed from current research on infant cognition (see, e.g., Baillargeon, 1993, 1995; Baillargeon et al., 1985; Kellman & Spelke, 1983; Spelke et al., 1992). Intercoder reliability was assessed on one third of all test trials that were included in the analysis. Percent agreement between coders was greater than .94.

Results

Overall, analysis of looking time revealed that during test trials, infants at all ages looked significantly longer at the impossible compared to the possible orientation outcome. As shown in Figure 2, this trend was found in both the translation and the rotation conditions. An overall 3 (Age Group) × 2 (Condition: Translation or Rotation) × 3 (Test Order: 1st, 2nd, or 3rd Test Trial) × 2 (Orientation: Possible or Impossible Outcome) mixed design analysis of variance (ANOVA) yielded a marginally significant test order, $F(1,28) = 3.394, p = .08$, and, more importantly, a significant main effect of orientation outcome only, $F(1,29) = 33.328, p < .001$. No significant interactions with age, $F(2,27) < 1$ (see also Figure 3), gender, $F(1,28) < 1$, condition order, $F(1, 28) < 1$, or starting orientation, $F(1, 28) < 1$, were found. The

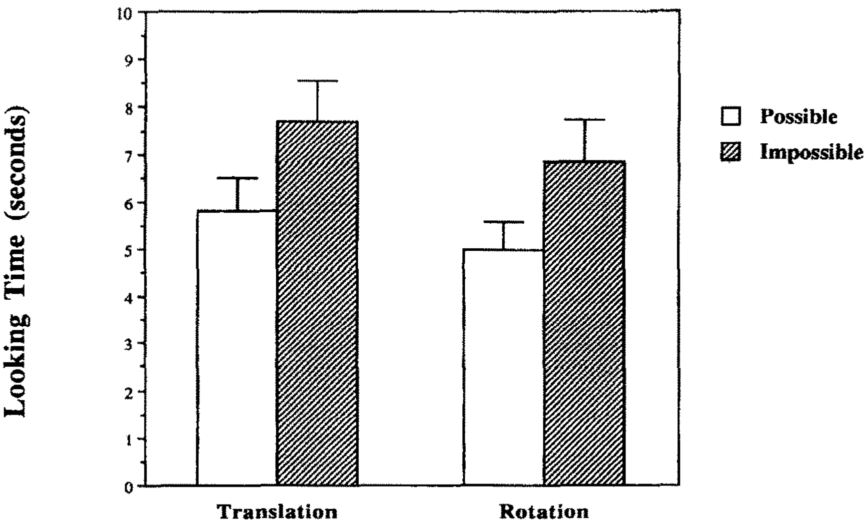

Figure 2. Overall mean looking time in seconds for the possible or impossible orientation outcome during test trials in the translation and rotation conditions of Experiment 1.

marginally significant effect of test order indicated that infants tended to be less engaged visually over test time (i.e., overall decrease in looking duration across the three test trials). However, the longer looking time at the impossible events remained, despite this trend.

These results were further supported by nonparametric statistics showing that overall, 26 out of the 30 subjects on average looked longer at the impossible compared to the possible orientation outcome (binomial test for probability, $p < .01$). This pattern was upheld in each age group: 7 of 10 for the 4-month-old infants, 10 of 10 for the 6-month-olds, and 9 of 10 for the 8-month-olds.

Discussion

Both parametric and nonparametric analyses demonstrated that infants discriminated the impossible from the possible outcome for both the translational and rotational displacement of the object behind the occluder. This phenomenon did not appear to depend on age, gender, condition order, test order, or starting orientation. From 4 months of age, infants showed that based on motion-specific information (i.e., translation or rotation), they are capable of mentally tracking an object undergoing invisible spatial transformations and anticipating the outcome of these transformations.

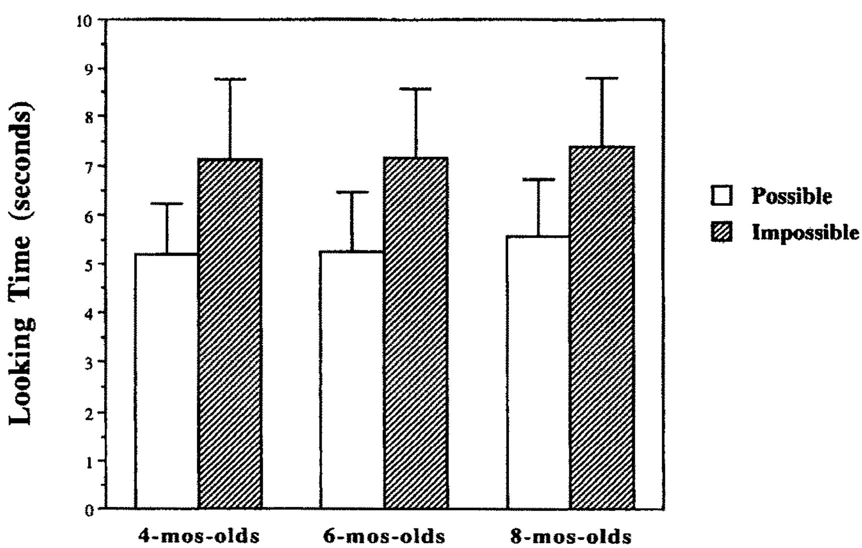

Figure 3. Overall mean looking time in seconds for the possible or impossible orientation outcome during test trials for the three different age groups in Experiment 1.

EXPERIMENT 2

A second experiment was performed to try to replicate the results obtained in Experiment 1, controlling for perceptual cues that infants might have picked up to anticipate the orientation outcome of the object, independently of any mental tracking of the invisible spatial transformations. The apparatus was modified to control for possible orientation cues from the display. In the translation condition, the vertical Plexiglas track was removed and in the rotation condition the radial arm was covered. The rationale for this modification was that in the first experiment infants might have compared the start and end orientation of the object merely on the basis of the relation between either the vertical track and the object (translation condition), or the radial arm and the object (rotation condition). Indeed, it is possible that infants perceived the vertical track and the object, or the radial arm and the object either as a single unit, or in terms of their invariant relationship. In this case, the results of Experiment 1 could be explained by the infant's reaction to either the novelty of the object, or the inconsistent relationship between the object and its support. Both of these cues could be used directly by the infant without requiring any tracking of the object's invisible spatial transformations.

Method

Participants. Twenty full-term healthy infants participated in the experiment. They were divided into two groups: ten 4-month-olds (2 girls and 8 boys, with a mean age of 4 months, 14 days ranging from 4 months, 5 days to 5 months, 5 days), and ten 6-month-olds (5 girls and 5 boys, with a mean age 6 months, 11 days ranging from 6 months, 0 day to 6 months, 30 days). Three additional babies were tested but not included in the final sample due to fussiness (1) or experimenter's error (2).

Apparatus and Scoring. These were the same as Experiment 1, except for the following modification of the apparatus. In the translation condition, the vertical Plexiglas track used in Experiment 1 was replaced. Instead, and in order to guide the object in its vertical trajectory to the bottom of the stage, a long vertical slot was cut into the felt backdrop of the stage. An 8-cm screw (0.4 cm in diameter) was protruding out the back of the object (invisible to the infant) and inserted into the vertical slot. The screw protruded through the backdrop's slot and was tightened to a wooden block held by the experimenter backstage for control of its motion and final orientation. In the rotation condition, a round, 73-cm diameter disk held by Velcro strips was placed in front of the radial arm to hide it. The disk was covered with the same black felt used for the backdrop. Infants now perceived the object rotating with no visible arm, orbiting 180° around the edge of the disk. The object was identical to the one used in Experiment 1.

Procedure. The procedure was the same as that in Experiment 1, except that the noise of the object landing on the stage behind the occluder in the translation condition was suppressed, as it could potentially be an auditory cue used by the infant to detect what happened to the object once it disappeared behind the occluder. The object was not merely dropped, but moved down at a constant velocity (count of 5 s from top to bottom of the stage) by the experimenter holding the object from behind the stage. There was no noisy impact of the object marking the end of the transformation. The constant velocity and duration of the object in the translation condition matched the motion characteristic of the object in the rotation condition. Intercoder reliability was assessed on one third of all test trials that were included in the analysis. Percent agreement between coders was greater than .93.

Results

Overall, analysis of first gaze duration confirmed the results obtained in the first experiment, revealing that during test trials, infants at both ages looked significantly longer at the impossible compared to the possible orientation outcome. This trend was found in both the translation and the rotation. An overall 2 (Age Group) × 2 (Condition: Translation or Rotation) × 3 (Test Order: 1st, 2nd, or 3rd Test Trial) × 2 (Orientation: Possible or Impossible Outcome) mixed design ANOVA yielded a significant main effect of test order, $F(2, 18) = 5.410, p < .009$, a significant main effect of orientation outcome $F(1, 18) = 7.731, p < .012$, and no significant interactions. For both age groups, gaze duration tended to decrease significantly across test trials and infants demonstrated less overall visual engagement over time. More importantly, infants looked significantly longer at the impossible compared to the possible orientation outcome during the test. This main effect replicated what was found in Experiment 1, with no significant interaction with either age, $F(1, 18) < 1$, gender, $F(1, 18) < 1$, condition order, $F(1, 18) < 1$, starting orientation $F(1, 18) < 1$, or test order, $F(1, 18) = 3.394, p = .08$. We compared the results obtained in this experiment with those of Experiment 1, based on a 2 (Experiment 1 or 2) × 2 (Condition: Translation or Rotation) × 3 (Test Order: 1st, 2nd, or 3rd Test Trial) × 2 (Orientation: Possible or Impossible Outcome) mixed design ANOVA. This analysis yielded no significant experiment by orientation outcome interaction, $F(1, 39) = .948, p < .333$.

Again, the results were supported further by nonparametric statistics showing that overall, 17 out of the 20 infants on average looked longer at the impossible compared to the possible orientation outcome (binomial test for probability, $p < .01$). This pattern was upheld in each age group: 9 of 10 for the 4-month-old infants and 8 of 10 for the 6-month-olds.

Discussion

Again, both parametric and nonparametric analyses demonstrated that 4- and 6-month-old infants discriminated the impossible from the possible outcome for both the translational or rotational displacement of the object behind the occluder. This replication indicates that the phenomenon cannot be accounted for on the basis of a comparison of static perceptual cues specifying the object in relation to its support (i.e., the vertical track or the radial arm). Experiment 2 demonstrated that the phenomenon holds when such perceptual cues are eliminated. It provides further support for the interpretation that infants reacted to a violation of expectation regarding the orientation outcome of the object, and that this expectation is based on the mental tracking of the object by the infant as it either translated or rotated behind the occluder. These results suggested that infants did not merely respond perceptually to a novel (rigid) relation of the object to its support in the impossible test situation, but rather anticipated the possible orientation outcome of an invisible transformation they tracked mentally.

EXPERIMENT 3

A final counterhypothesis was considered in a third experiment. It is possible—at least in the translation condition—that infants merely compared the start and end orientation of the object without detecting and using motion information. To test this interpretation, and in particular to check whether infants might form expectations without using motion information, a control experiment was performed. In this control experiment, the same general procedure was used except that there was no continuous transformation between the start and final orientation of the object. Again, the question was whether infants would form expectations about the final orientation of the object independently of the continuous spatial transformation.

Method

Participants. Nine 6-month-old full-term healthy infants (5 boys and 4 girls, M = 6 months, 21 days; range 6 months, 6 days to 7 months, 9 days) served as participants.

Apparatus and Scoring. This was the same as for Experiment 1 (see earlier Method section).

Procedure. During the experiment, the infant sat on the parent's lap facing the stage. Again, the parent was asked not to interact with the infant, holding him or her gently by the hips. Infants were tested in a single condition where they were shown the same object as the one used in Experiment 1. The infant first was shown six successive familiarization trials, with the object presented at the top of the stage (starting position). Once the infant had fixated the object for approximately 2 s, the experimenter removed the object. Following the six familiarization trials, there were six test trials. During the test, the experimenter once again presented the object at the top of the stage (starting orientation), then removed the object and placed it on the stage floor behind the occluder, via the hidden trap door (see apparatus section of Experiment 1). Note that this transport was invisible to the infant. The occluder was then lowered, revealing the object in either a matching or nonmatching orientation relative to the starting orientation. As in Experiment 1, the nonmatching orientation corresponded to a 180° inversion of the starting orientation. From the moment the screen was lowered, looking time at the revealed object was measured based on a close-up video recording of the infant's face (see apparatus section of Experiment 1). When the infant looked away from the object for 2 consecutive seconds, the screen was raised and a new test trial began. For each infant, there were six test trials alternating between matching and nonmatching orientation. The starting orientation and the order of the test were counterbalanced among subjects.

Results

Overall, analysis of first gaze duration revealed that infants tended to look equally at the matching and nonmatching orientation during test trials. A 3 (Test Order) × 2 (Orientation Outcome) ANOVA with repeated measures yielded no significant main effect of orientation outcome, $F(1, 8) = 1.180, p = .31$, no significant main effects of order, $F(1, 8) < 1$, or any significant interaction. These results were further confirmed by nonparametric statistics. Overall, five out of the nine infants looked longer on average at the matching orientation, and four at the nonmatching orientation. These results indicated that in the absence of transformational motion, infants do not show any specific anticipation of the final orientation outcome.

General Discussion

The results of Experiment 1 demonstrate that 4- to 8-month-old infants discriminated between the possible and impossible orientation outcome of an object disappearing by either translating or rotating behind the opaque screen. Following the spatial transformation, and when the screen was lowered to reveal the object, infants looked significantly longer at the impossible, compared to the possible final orientation of the object. These results cannot be accounted for based on an intrinsic preference for the object in a particular orientation. In the translation condition, where the starting and final possible orientation of the object was the same, infants' reactions to the impossible orientation could have corresponded to a reaction to the novelty of this orientation, rather than its impossibility. Results in the rotation condition go against this interpretation as the starting and final possible orientations were different. Results in the rotation condition demonstrate that infants reacted to the impossibility of the final orientation, and not merely to its novelty in comparison to the starting orientation. Furthermore, the negative results obtained in Experiment 3 with no motion provide further support that infants did not react on the basis of a comparison between the static starting and final orientation of the object. Taken together, these results indicate that in Experiment 1, infants' reactions were based on motion-specific information.

Longer looking time at the impossible outcome also suggests that infants mentally tracked the object as it moved behind the occluder. In the translation condition, infants saw the object falling behind the occluder, then only heard it land on the stage floor. In the rotation condition, infants saw the object disappear behind the occluder at 4 o'clock, then saw the visible part of the rotating arm (black metal rod against the black background) continue to rotate and silently stop at 6 o'clock. In both conditions, infants were provided with some auditory or visual information that the object did continue to move once occluded, and where it stopped.

In Experiment 2, a leaner interpretation of these results was tested. The apparatus used in Experiment 1 left open the possibility that the infants' longer looking at the impossible outcome was based on the direct perception of a change in the relation between the object and its support (vertical track or rotating arm). Accordingly, this would not require the infant to either track the object as it moved behind the occluder or to anticipate its orientation outcome. The results of Experiment 2 clearly reject such possibility, and replicate those of Experiment 1, controlling for the perceptual cues specifying the relation of the object to its support.

As seen in the introduction, the recent works of Spelke et al. (1992) and Baillargeon (1993) provide ample documentation of young infants' ability to conceive the location and behavior of objects that are temporarily out of sight. What is new and remarkable in the results here is that they provide support for the demonstration that young infants can mentally track invisible transformations of an object and can infer changes in its spatial orientation. This appears to be based on a precocious ability to generate dynamic mental imagery. We suggest that the discrimination between possible and impossible outcomes of the transformation can only be based on the tracking of the object's orientation before, during, and after its disappearance. In the rotation condition, infants had to track the object while it continued to rotate behind the occluder. The results obtained in this latter condition provide first support for rudiments of mental rotation by infants as young as 4 months. Future studies should investigate further the determinants and development of this ability in early infancy.

REFERENCES

Baillargeon, R. (1993). The object concept revisited: New directions in the investigation of infants' physical knowledge. In C.E. Granrud (Ed.), *Visual perception and cognition in infancy* (pp. 265–316). Hillsdale, NJ: Erlbaum.

Baillargeon, R. (1995). Physical reasoning in infancy. In M.S. Gazzaniga (Ed.), *The cognitive neurosciences* (pp. 181–204). Cambridge, MA: MIT Press.

Baillargeon, R., Spelke, E.S., & Wasserman, S. (1985). Object permanence in five-month-old infants. *Cognition, 20*, 191–208.

Clifton, R., Rochat, P., Litovsky, R., & Perris, E. (1991). Object representation guides infants' reaching in the dark. *Journal of Experimental Psychology: Human Perception and Performance, 17*(2), 323–329.

Kellman, P.J., & Spelke, E.S. (1983). Perception of partly occluded objects in infancy. *Cognitive Psychology, 15*, 483–524.

Piaget, J. (1954). *The construction of reality in the child.* New York: Basic Books.

Piaget, J., & Inhelder, B. (1971). *Mental imagery in the child.* New York: Basic Books.

Spelke, E.S., Breinlinger, K., Macomber, J., & Jacobson, K. (1992). Origins of knowledge. *Psychological Review, 9*(4), 605–632.

Xu, F. (1993, April). *The development of object identity in infancy.* Poster presented at the Society for Research and Child Development, New Orleans, LA.