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The Object Concept Revisited: New Directions in the Investigation of Infants' Physical Knowledge

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An important concern of cognitive psychology in recent years has been the description of children's and adults' physical knowledge. This research has focused on three important questions. First, investigators have sought to describe the *content* of children's and adults' knowledge. Physical domains that have been examined include astronomy (Vosniadou & Brewer, 1989), biology (Carey, 1985), and physics (Clement, 1982; D. Gentner & D. R. Gentner, 1983; Karmiloff-Smith & Inhelder, 1975; McCloskey, 1983; Siegler, 1978). Second, researchers have attempted to elucidate the *structure* of children's and adults' physical knowledge. Different models have been proposed, ranging from lists of local rules to naive models or "theories" organized around causal principles (Carey, 1985; Gelman, 1990; D. Gentner & Stevens, 1983; Keil, 1990; Siegler, 1978, 1983; Vosniadou & Brewer, 1989; Wellman, in press). Finally, investigators have been concerned with the *development* of children's and adults' physical knowledge. Of particular interest has been the comparison of novices' and experts' representations of physical domains (Chi, Feltovitch, & Glaser, 1981; Larkin, 1983; Wiser & Carey, 1983).

In the realm of infancy research, investigators have also sought to characterize infants' physical world. Most of this research has focused on issues of content, and more specifically, on infants' understanding of occlusion events. When adults see an object occlude another object, they typically make three assumptions. The first is that the occluded object continues to exist behind the occluding object. The second is that the occluded object retains the spatial and physical properties it possessed prior to occlusion. The third is that the occluded object is still subject to physical laws; its displacements, transformations, and interactions with other objects do not become capricious or arbitrary but remain regular and predictable. Collectively, these assumptions are generally referred to in the developmental literature as a concept of *object permanence* or, more broadly, as an *object concept.*

Piaget (1954) was the first to investigate whether infants share adults' assumptions about occluded objects—or, in other words, whether infants possess a notion of object permanence. Detailed analyses of infants' performances on manual search tasks led him to conclude that the development of infants' beliefs about occluded objects progresses through six stages and is not complete until 2 years of age.

Piaget's theory of the development of infants' beliefs about occluded objects has occupied a central position in the field of infant cognition (e.g., Flavell, 1985; Harris, 1983). The acquisition of a notion of object permanence is often considered to be the cornerstone of cognitive development in infancy, and indeed, what could be more basic than the object concept? The realization that visible and occluded objects exist in the same objective space and obey the same physical laws constitutes one of the fundamental tenets on which our representation of the physical world is built. It is not surprising, therefore, that considerable effort has been expended since the publication of Piaget's theory to confirm and extend his conclusions (see Bremner, 1985; Gratch, 1975, 1976; Harris, 1987, 1989; Schuberth, 1983; Sophian, 1984; Spelke, 1988; and Wellman, Cross, & Bartsch, 1987, for reviews).

Since the early 1980s, my collaborators and I have conducted an extensive series of experiments on young infants' understanding of occlusion events. In these experiments, we have used visual tasks rather than the manual search tasks used by Piaget and his followers. The selection of visual tasks stemmed from a concern that infants might perform poorly in manual search tasks, not because their concept of object permanence was underdeveloped, but because their ability to plan search action sequences was limited. Some of the experiments we carried out were designed expressly as tests of Piaget's theory; others focused on hitherto unexplored aspects of infants' understanding of occlusion events. In general, the results of these experiments paint a radically different picture of infants' ability to represent and to reason about occluded objects than that bequeathed by Piaget and, until recently, adopted by most developmental psychologists. Indeed, the results suggest that young infants' understanding of occlusion events is strikingly similar to that of adults.

This chapter is divided into four sections. The first section presents Piaget's description of the sequence of changes in infants' beliefs about occluded objects, and the evidence on which this description was based. The second section reviews the experiments we have conducted to test Piaget's theory and to pursue new directions suggested by the results of these initial tests. The third section considers possible explanations for the marked discrepancy between search and non-search assessments of infants' understanding of occlusion events. Finally, the last section examines the implications of the present research for descriptions of the content, structure, and development of infants' physical knowledge.

PIAGET'S THEORY

Piaget (1954) proposed that infants' beliefs about occluded objects develop through six stages. During the first three stages (0 to 9 months), infants do not realize that objects continue to exist when occluded: They assume that objects cease to exist when they cease to be visible and begin to exist anew when they come back into view. According to Piaget, the object at this stage is "a mere image which reenters the void as soon as it vanishes, and emerges from it for no objective reason" (1954, p. 11). During the fourth stage (9 to 12 months), infants begin to view objects as permanent entities that continue to exist when masked by other objects. However, this permanence is still limited. Infants do not yet conceive of occluded objects as occupying objective locations in space. It is not until the fifth stage (12 to 18 months), Piaget maintained, that infants begin to systematically attend to visible displacements and to assume that occluded objects reside in whatever locations they occupied immediately prior to occlusion. The sixth stage (18 to 24 months), which is signaled by the emergence of symbolic representation, constitutes the final advance in the development of infants' beliefs about occluded objects. Because of their new representational capacity, infants become able to imagine invisible displacements and hence to infer, as opposed to merely represent, occluded objects' locations. According to Piaget, objects' appearances and disappearances are then no longer mysterious but follow known, predictable patterns. By the end of the sixth stage, the 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 occluded objects, existing in a unitary, objective space, and obeying the same physical laws.

As was mentioned earlier, the main evidence for Piaget's description of the sequence of changes in infants' beliefs about occluded objects came from studies of the development of manual search behavior. Thus, Piaget's first claim, that is not until about 9 months of age that infants begin to endow objects with permanence, was based on the finding that manual search does not emerge until this age. Piaget noted that, prior to Stage 4, infants do not search for objects they have observed being hidden. If a toy is covered with a cloth, for example, they make no attempt to lift the cloth and grasp the toy, even though they are capable of performing each of these actions. Beginning in Stage 4, however, infants do remove obstacles to retrieve hidden objects.

Why did Piaget select infants' willingness to search for hidden objects as marking the beginning of object permanence? This question is important because

Piaget observed several behaviors prior to Stage 4 that are suggestive of object permanence. For example, he noted that, as early as Stage 1 (0 to 1 month), infants may look at an object, look away from it, and then return to it several seconds later, without any external cue having signaled the object's continued presence. In addition, Piaget observed that,beginning in Stage 3 (4 to 9 months), infants anticipate the future positions of moving objects. If they are tracking an object and temporarily lose sight of it, they look for it further along its trajectory; similarly, if they are holding an object out of sight and accidentally let go of it, they stretch their arm to recapture it.

Piaget held that although these and other behaviors seem to reveal a notion of object permanence, closer analysis indicates "how superficial this interpretation would be and how phenomenalistic the primitive universe remains" (1954, p. 11). Prior to Stage 4, Piaget maintained, infants lack a concept of physical causality and regard all of reality as being dependent on their activity. When acting on an object, infants view the object not as an independent entity but as the extension or the product of their action. If the object disappears from view, infants reproduce or extend their action because they expect that this action will again produce the object. Proof for Piaget that infants regard the object as being "at the disposal" of their action is that if their action fails to bring back the object, they do not perform alternative actions to recover it. Beginning in Stage 4, however, infants act very differently. For example, if a ball rolls behind a cushion and they cannot recapture it by extending their reach, they try alternative means for recovering it: They lift the cushion, pull it aside, or grope behind it. According to Piaget, such activities indicate that infants conceive of the object, not as a thing at the disposal of a specific action, but as a substantial entity that is located out of sight behind the cushion and that any of several actions may serve to reveal.

Piaget's second claim, that it is not until about 12 months of age that infants begin to conceive of occluded objects as occupying objective locations in space, was suggested by the finding that perseverative search errors do not disappear until this age. Piaget noted that when Stage 4 infants search for hidden objects, they often search in the wrong location. Specifically, if an object is hidden in a location A and, after infants have retrieved it, the same object is hidden in a new location B, infants tend to search for the object in A, where they first found it. Piaget took these errors to indicate that, although infants endow the object with permanence, as evidenced by their willingness to search for it, this permanence is not yet complete. Infants still regard the object as the extension of their action: When the object disappears at B, they search for it at A because they expect that by reproducing their action at A they will again produce the object. According to Piaget, "in all the observations in which the child searches in A for what he as seen disappear in B, the explanation should be sought in the fact that the object is not yet sufficiently individualized to be dissociated from the global behavior related to position A" (1954, p. 63). Beginning in Stage

5, however, infants do search for objects where they were last seen, rather than where they were first found. According to Piaget, infants are becoming aware that objects reside not in special positions linked to their own actions, but in objective locations resulting from the objects' displacements within the visual field.

Finally, Piaget's third claim, that it is not until about 18 months of age that infants begin to infer the location of occluded objects, was based on the discovery that it is not until this age that infants succeed at search tasks involving invisible displacements. In these tasks, an object is hidden, in full view of the infant, in a small container, which is then moved behind each of several screens. The object is surreptitiously left behind one of the screens, usually the last. Piaget found that when asked to find the object, Stage 5 infants typically search the container, the location where they last saw the object. Failing to find the object there, they make no attempt to search behind the screens. Beginning in Stage 6, however, infants do search behind the screens. Piaget speculated that because of their new-found representational abilities, infants are able to imagine or to infer the object's probable displacements. Piaget described the transition from Stage 5 to Stage 6 in these terms:

> A world [such as the world of the fifth stage infant] in which only perceived movements are regulated is neither stable nor dissociated from the self; it is a world of still chaotic potentialities whose organization begins only in the subject's presence . . . [The] representation and deduction characteristic of the sixth stage result in extending the process of solidification to regions . . . which are dissociated from action and perception; displacements, even invisible ones, are henceforth envisaged as subservient to laws, and objects in motion become real objects independent of the self and persisting in their substantial identity. (Piaget, 1954, p. 86)

TEST OF PIAGET'S THEORY

Since the early 1980s, my collaborators and I have conducted an extensive series of experiments on young infants' understanding of occlusion events. This section summarizes the results of these experiments. The section is organized into three parts. The first reports experiments on young infants' ability to represent the existence of occluded objects; the second reviews experiments on young infants' ability to represent the spatial and physical properties of occluded objects; and the third presents preliminary experiments on young infants' ability to make inferences about the existence and properties of occluded objects.

Representing the Existence of Occluded Objects

During the 1960s and 1970s, Piaget's (1954) observation that young infants do not search for hidden objects was confirmed by many investigators (see Gratch, 1975, 1976, for reviews of this early work). Nevertheless, Piaget's interpretation of this observation was questioned. It was proposed that young infants might fail to search for hidden objects, not because of a lack of object permanence, but because of difficulties associated with manual search (e.g., Bower, 1974).

This analysis suggested that young infants might show evidence of object permanence if given tests that did not require manual search. Bower (1967, 1972, 1974; Bower, Broughton, & Moore, 1971; Bower & Wishart, 1972) devised several such tests and obtained three results that seemed indicative of object permanence in young infants. First, 7-week-old infants were found to discriminate between disappearances that signaled the continued existence of an object (e.g., gradual occlusions), and disappearances that did not (e.g., gradual dissolutions or sudden implosions; Bower, 1967). Second, 2-month-old infants were found to anticipate the reappearance of an object that stopped behind a screen, "looking to that half of the movement path the object would have reached had it not stopped" (Bower et al., 1971, p. 183). Finally, 5-month-old infants were found to show disruptions in their tracking when an object was altered while passing behind a screen: They tended to look back at the screen, as though in search of the original object (Bower, 1974; Bower et al., 1971).

Although suggestive, Bower's three results did not provide conclusive evidence of object permanence in young infants. First, methodological problems cast doubts on the validity of the results (e.g., Baillargeon, 1986, 1987b; Baillargeon, Spelke, & Wasserman, 1985; Goldberg, 1976; Gratch, 1975, 1976, 1982; Harris, 1987; Hood & Willatts, 1986; Meicler & Gratch, 1980; Muller & Aslin, 1978). Second, the results were open to alternative interpretations that did not implicate object permanence. In particular, the last two results could be explained by Piagetian theory in terms of the extension of an ongoing action or the reproduction of a previous action. When anticipating the reappearance of the object, the infants could simply have been extending a tracking motion begun prior to the object's disappearance. Furthermore, when looking back at the screen, after the novel object had emerged from behind it, the infants could have been repeating their prior action of looking in that direction, with the expectation that this action would again produce the original object.

The first of Bower's (1967) results could not be explained in terms of the extension or the reproduction of an action, but it, too, was open to alternative interpretations. One such interpretation was that the infants discriminated between the test disappearances on the basis of superficial expectations about the way objects typically disappear, rather than on the basis of a belief in object permanence. In their daily environment, infants often see objects occlude one another but they rarely, if ever, see objects implode or dissolve into the air. Hence, the infants could have responded differently to the occlusions than to the implosions or the dissolutions simply because the occlusions represented the only type of disappearance that was familiar to them.

Because of the difficulties associated with Piaget's and Bower's tasks, my colleagues and I sought a new means of testing object permanence in young infants (Baillargeon et al., 1985). Like Bower, we chose not to rely on manual search as an index of object permanence. However, we tried to find an index that did not depend on (a) the extension or reproduction of an action or (b) knowledge about superficial properties of object disappearances.

The method we devised focused on infants' understanding of the principle that a solid object cannot move through the space occupied by another solid object. We reasoned that if infants were surprised when a visible object appeared to move through the space occupied by another, occluded object, it would suggest that they took account of the existence of the occluded object.

In a series of experiments, 5½-month-olds (Baillargeon et al., 1985) and 4½-month-olds (Baillargeon, 1987a) were habituated to a screen that rotated back and forth through a 180° arc, in the manner of a drawbridge (see Fig. 9.1). Following habituation, a box was placed behind the screen and the infants saw a possible and an impossible test event. In the possible event, the screen stopped when it reached the occluded box; in the impossible event, the screen rotated through a full 180° arc, as though the box were no longer behind it. Both the 5½- and the 4½-month-old infants looked reliably longer at the impossible than at the possible event, suggesting that they (a) represented the existence of the box behind the screen; (b) understood that the screen could not rotate through the space occupied by the box; and hence (c) expected the screen to stop and were surprised in the impossible event that it did not.

There was, however, an alternative interpretation for the results. The infants could have looked longer at the impossible than at the possible event simply because they found the 180° screen rotation more interesting that the shorter rotation used in the possible event. To check this interpretation, we tested additional groups of infants in a control condition that was identical to the experimental condition except that no box was placed behind the screen. The infants now looked equally at the two screen rotations. This finding provided evidence that the infants in the experimental condition looked longer at the impossible event, not because they preferred the 180° screen rotation, but because they expected the screen to stop and were surprised that it did not.

In other experiments also reported in Baillargeon (1987a), 3½-month-old infants were examined using the same paradigm. The results indicated that the infants who were fast habituators[1] looked reliably longer at the impossible

[1]In this experiment, an infant received habituation trials until (a) the infant reached a criterion of habituation of a 50% or higher decrease in looking time on three consecutive trials relative to his or her looking time on the first three trials, or (b) the infant completed nine trials without satisfying the habituation criterion. Therefore, the minimum number of habituation trials an infant could receive was six, and the maximum number was nine. Infants who took six or seven trials to reach the habituation criterion were classified as *fast* habituators; infants who required eight or nine trials to reach the criterion or who failed to reach the criterion within nine trials were classified as *slow* habituators.

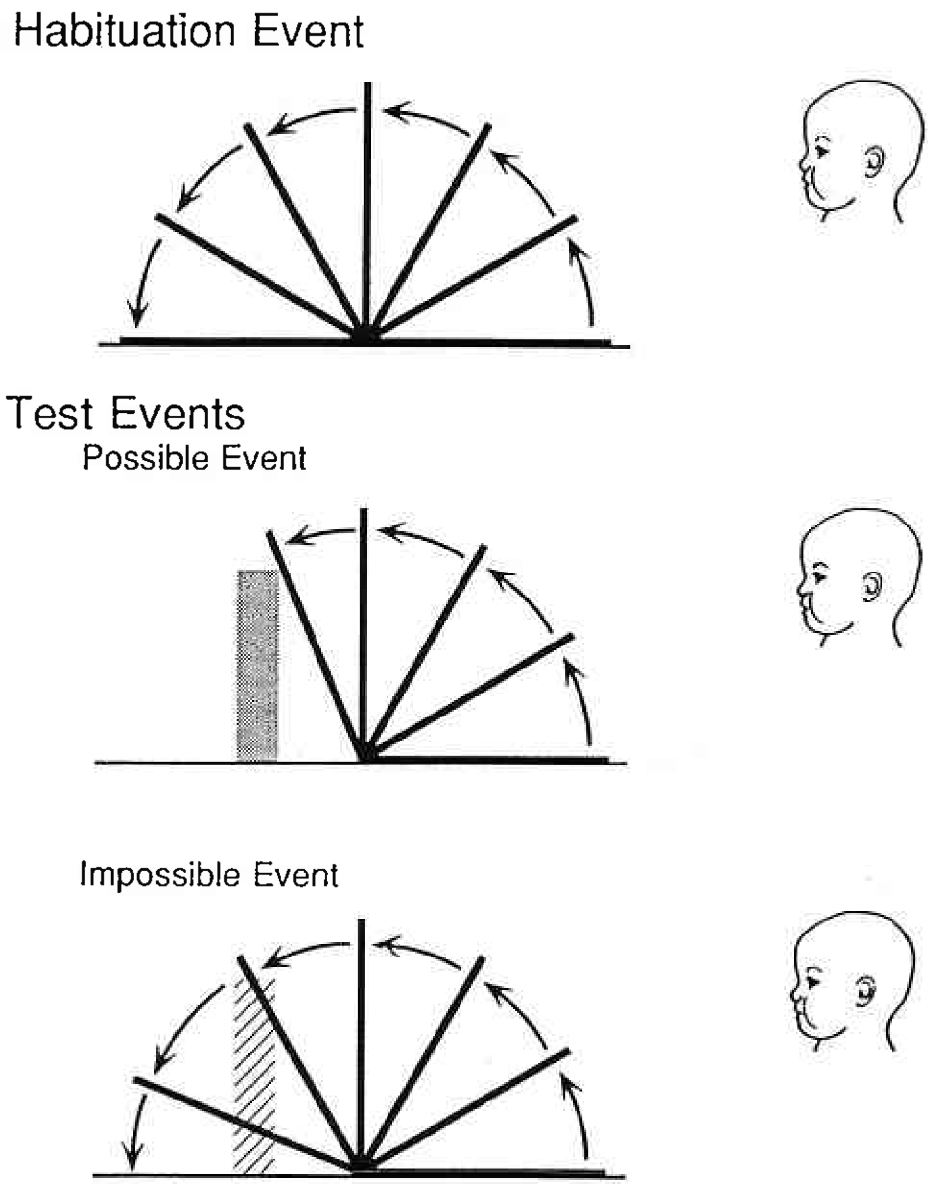

FIG. 9.1. Schematic drawing of the events shown to the infants in Baillargeon et al. (1985) and in Baillargeon (1987a).

than at the possible event, whereas the infants who were slow habituators looked equally at the two events. These findings suggested that, like the 5½- and the 4½-month-old infants in the initial experiments, the 3½-month-old infants who were fast habituators expected the screen to stop and were surprised in the impossible event that it did not. A control condition conducted without the box supported this interpretation. The results of these experiments thus indicated that, contrary to what Piaget had claimed, infants as young as 3½ months of age represent the existence of occluded objects.

Representing the Properties of Occluded Objects

Location. The results presented in the last section indicated that infants represent the existence of occluded objects long before 9 months of age. Such a finding raised the possibility that infants represent the location of occluded objects—the next step in Piaget's (1954) developmental sequence—before the age of 12 months. To examine this possibility, 6½- and 8-month-old infants were tested using a novel paradigm (Baillargeon, 1986). The infants sat in front of a screen; to the left of the screen was a long inclined ramp (see Fig. 9.2). The infants were habituated to the following event: The screen was raised (to show the infants that there was nothing behind it) and then lowered; a toy car then rolled down the ramp, passed behind the screen, and exited the apparatus to the right. Following habituation, the infants saw a possible and an impossible test event. These events were identical to the habituation event except that a box was placed behind the screen. In the possible event, the box stood in back of the car's tracks; in the impossible event, the box stood on top of the tracks, blocking the car's path.

The results indicated 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 similar results. Together, these results indicated that the infants (a) represented the location of the box behind the screen; (b) assumed that the car pursued

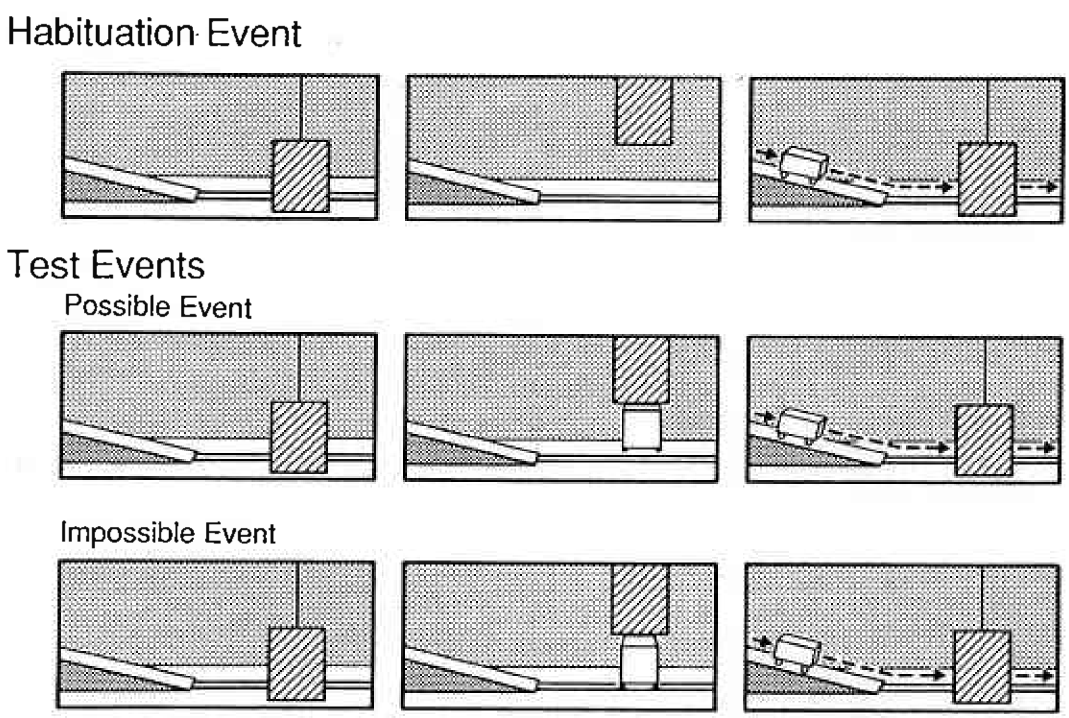

FIG. 9.2. Schematic drawing of the events shown to the infants in Baillargeon (1986) and in Baillargeon and DeVos (1991, Exp. 3).

its trajectory behind the screen; (c) understood that the car could not roll through the space occupied by the box; and hence (d) were surprised in the impossible event to see the car roll past the screen.

In subsequent experiments, 4-month-old infants were tested using a similar procedure, except that the box was replaced by a toy mouse (Baillargeon & DeVos, 1991). The results showed that the *male* infants tended to look equally at the test events; in contrast, the *female* infants looked reliably longer when the toy mouse stood on top of the car's tracks than when it stood either in back or in front of the tracks. (This is no doubt the first evidence of female superiority in reasoning about cars! See Baillargeon & DeVos, 1991, for interpretations of this unexpected sex difference.) The results obtained with the female infants indicated that, like the 6½- and the 8-month-old infants in the original experiments, these younger infants were surprised to see the car reappear from behind the screen when the mouse stood in its path.

The results of these experiments thus indicated that, contrary to what Piaget had claimed, infants as young as 4 months of age assume that objects retain their locations when occluded.

Additional Properties. The experiments described in this section asked whether infants could represent not only the location but also the height and the compressibility of occluded objects.

The first experiment in this series examined 7½-month-old infants' ability to represent the height and the location of a hidden object (Baillargeon, 1987b). The infants were habituated to a screen that rotated back and forth through a 180° arc (see Fig. 9.3). Following habituation, the infants saw a possible and an impossible test event. In both events, a box was placed behind the screen, which rotated back and forth through a 165° arc. The only difference between the events was in the orientation and location of the box behind the screen. In the possible event, the box lay flat 10 cm behind the screen and was 4 cm high; in the impossible event, the box stood upright 25 cm behind the screen and was 20 cm high. The 165° rotation of the screen was consistent with the horizontal orientation of the box (the screen stopped rotating when it reached the box), but not with its vertical orientation (the screen rotated through the space occupied by the top 14 cm or 70% of the box).

The infants looked reliably longer at the impossible than at the possible event, suggesting that they (a) represented the height and location of the box behind the screen; (b) used this information to estimate at what point the screen would reach the box; (c) understood that the screen could not rotate through the space occupied by the box; and therefore (d) were surprised when the screen continued to rotate after it reached the box. This interpretation was supported by a control condition in which the screen underwent a different motion (see Fig. 9.3). In the habituation event, the screen rotated upward 90° and then, remaining vertical, slid backward 30 cm. In the test events, the screen again rotated 90°

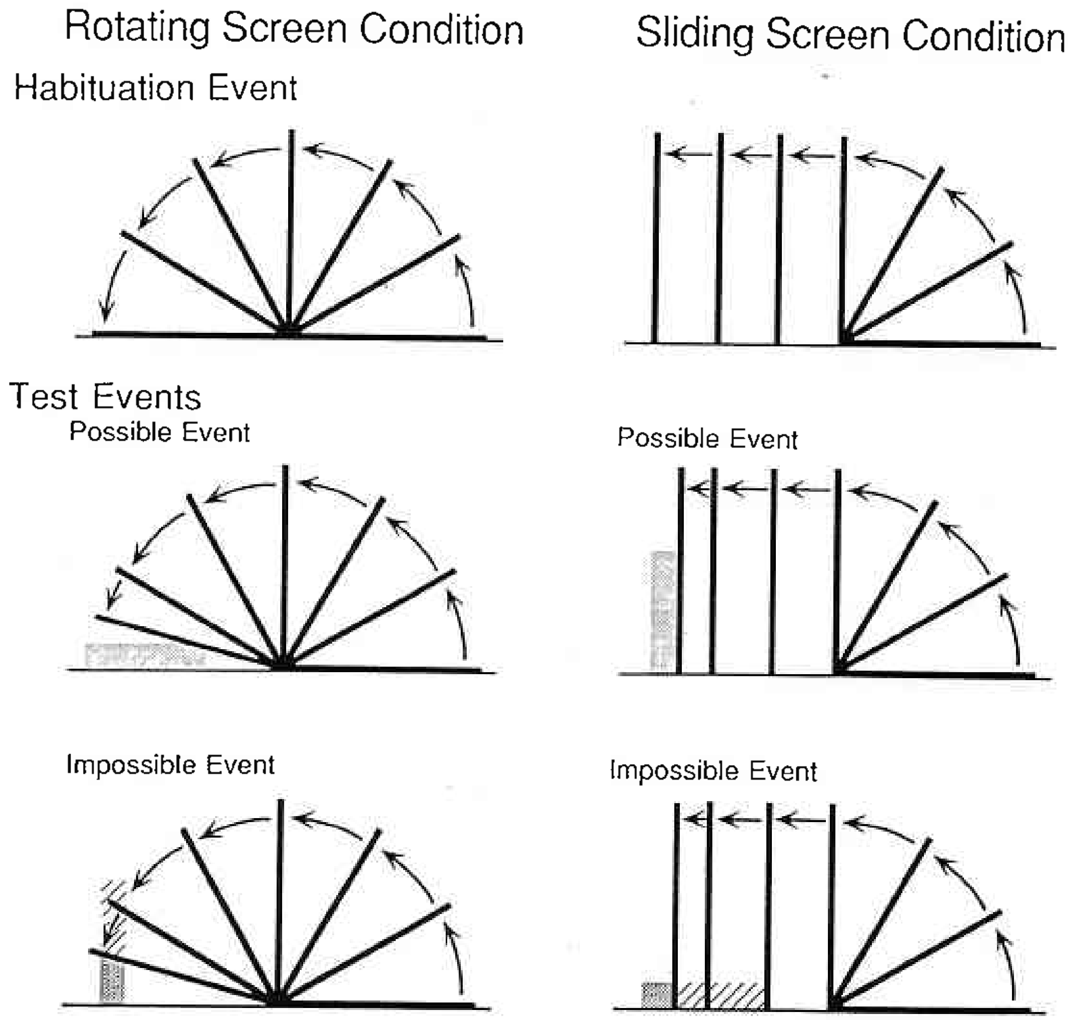

FIG. 9.3. Schematic drawing of the events shown to the infants in Baillargeon (1987b, Exp. 1).

but slid back 25 cm instead of 30 cm. As in the rotating screen condition, the box either stood upright 25 cm behind the screen (possible event), or lay flat 10 cm behind the screen (impossible event). The infants again looked reliably longer at the impossible than at the possible event. This result provided evidence that the infants in the rotating screen condition looked longer at the impossible event, not because they preferred the box in its vertical orientation, but because they were surprised that the screen continued rotating after it reached the box.

The next experiment (Baillargeon, 1987b) examined whether 7½-month-old infants could represent the compressibility as well as the height and location of a hidden object. The infants saw a possible and an impossible test event in which a screen rotated back and forth through a 157° arc (see Fig. 9.4). In the possible event, a soft, compressible object (an irregular ball of gauze) stood behind the screen, and in the impossible event, a hard, non-compressible ob-

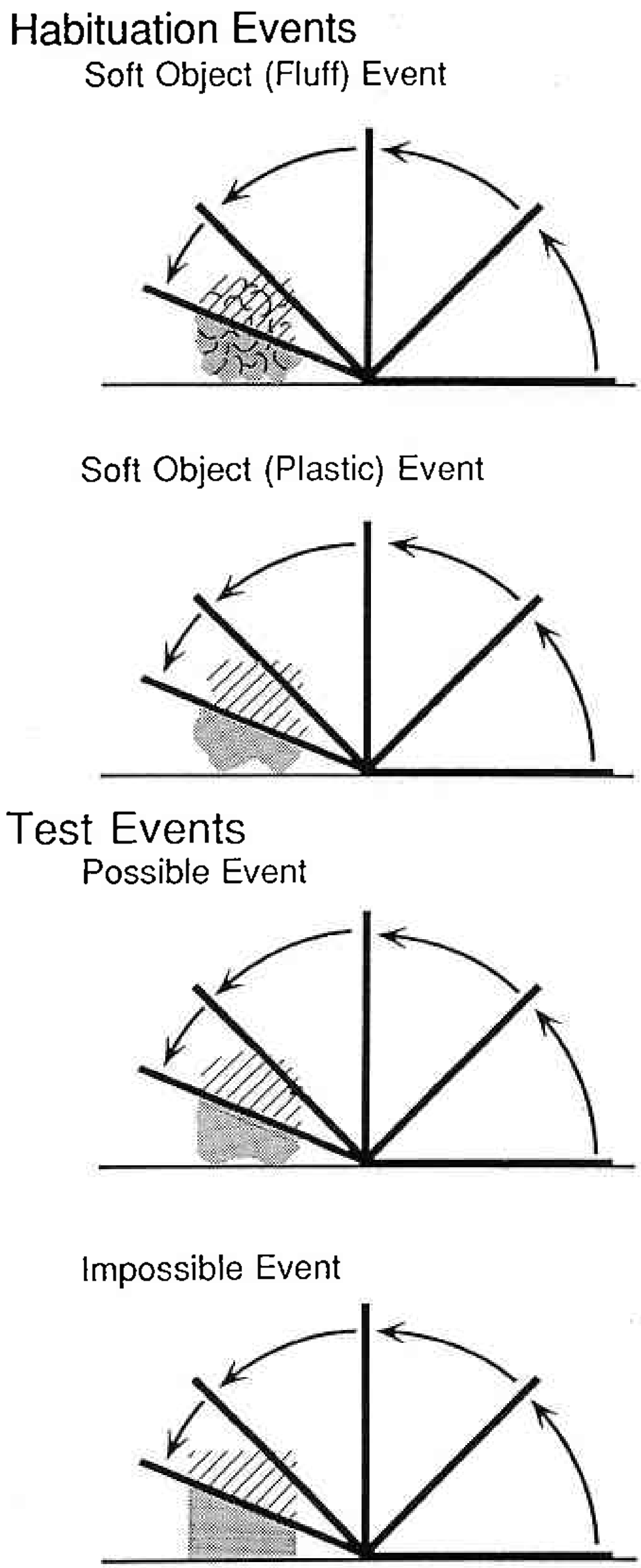

FIG. 9.4. Schematic drawing of the events shown to the infants in Baillargeon (1987b, Exp. 2).

ject (a wooden box) stood behind the screen (the infants were allowed to manipulate the test objects for a few seconds before the experiment began). The two objects were approximately the same color and size and they were placed at the same location behind the screen. The 157° rotation was consistent with the presence of the soft object (the screen could compress the object), but not with the presence of the hard object (the screen appeared to rotate through the space occupied by the top portion of the object). Prior to seeing the test events, the infants watched two habituation events that were identical to the possible event except that other soft objects were used (these were two irregular balls, one made of polyester stuffing and the other of plastic bags).

The infants looked reliably longer at the impossible than at the possible event, suggesting that they (a) represented the height and location of the object behind the screen, and used this information to decide at what point the screen would reach 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 hence (c) were surprised when the screen continued to rotate after it reached the hard object. This interpretation was supported by a control condition in which the screen rotated 112° instead of 157° and thus stopped before it reached the hard or soft object behind it. The infants in this condition tended to look equally at the test events. This finding provided evidence that the infants in the experimental condition looked longer at the impossible than at the possible event, not because they preferred the hard to the soft object, but because they were surprised that the screen continued to rotate after it reached the incompressible hard object.

Together, the results of these experiments suggested two conclusions. The first was that, by 7½ months of age, infants can represent the physical (e.g., height, compressibility) as well as the spatial (e.g., location) properties of occluded objects. The second was that infants this age can make both qualitative and quantitative predictions about occluded objects. The infants in the experiments not only realized *that* the screen should stop when an object blocked its path (qualitative prediction): They also were able to judge *at what point* the screen should stop, depending on the object's height, compressibility, and location (quantitative prediction). Following the terminology used in computational models of everyday physical reasoning (e.g., Forbus, 1984), the second prediction is said to be quantitative because it required the infants to compute a quantitative estimate of the screen's stopping point. Specifically, the infants had to determine how high above the apparatus floor the screen would be when it came to a stop. In contrast, the first prediction is referred to as qualitative because it embodied no quantitative judgments.

Developmental evidence. The next experiments asked two questions (Baillargeon, 1991). First, would younger infants, 6½- and 4½-month-olds, also be able to represent and to reason quantitatively about the height and location of an occluded object? Second, how precise was infants' quantitative reasoning? In Baillargeon's (1987b) experiment (shown in Fig. 9.3), the screen rotated through the top 70% of the space occupied by the occluded box—to adults, an obvious violation. Would infants still detect that the screen rotated farther than it should if it rotated through a smaller portion of the occluded box? The experiments compared infants' performances with 80% and 50% violations.

In the first experiment, 6½-month-old infants were habituated to a screen that rotated back and forth through a 180° arc (see Fig. 9.5). Following habituation, a box 25 cm tall was placed 12.5 cm behind the screen (as in Baillargeon, 1987a), and the infants saw a possible and an impossible test event. In the possible event, the screen stopped rotating before it reached the occluded box (112° arc); in the impossible event, the screen rotated through either the top 80% (157° arc) or the top 50% (135° arc) of the space occupied by the box.

The results indicated that the infants in the 80% rotation condition looked reliably longer at the impossible than at the possible event, whereas those in

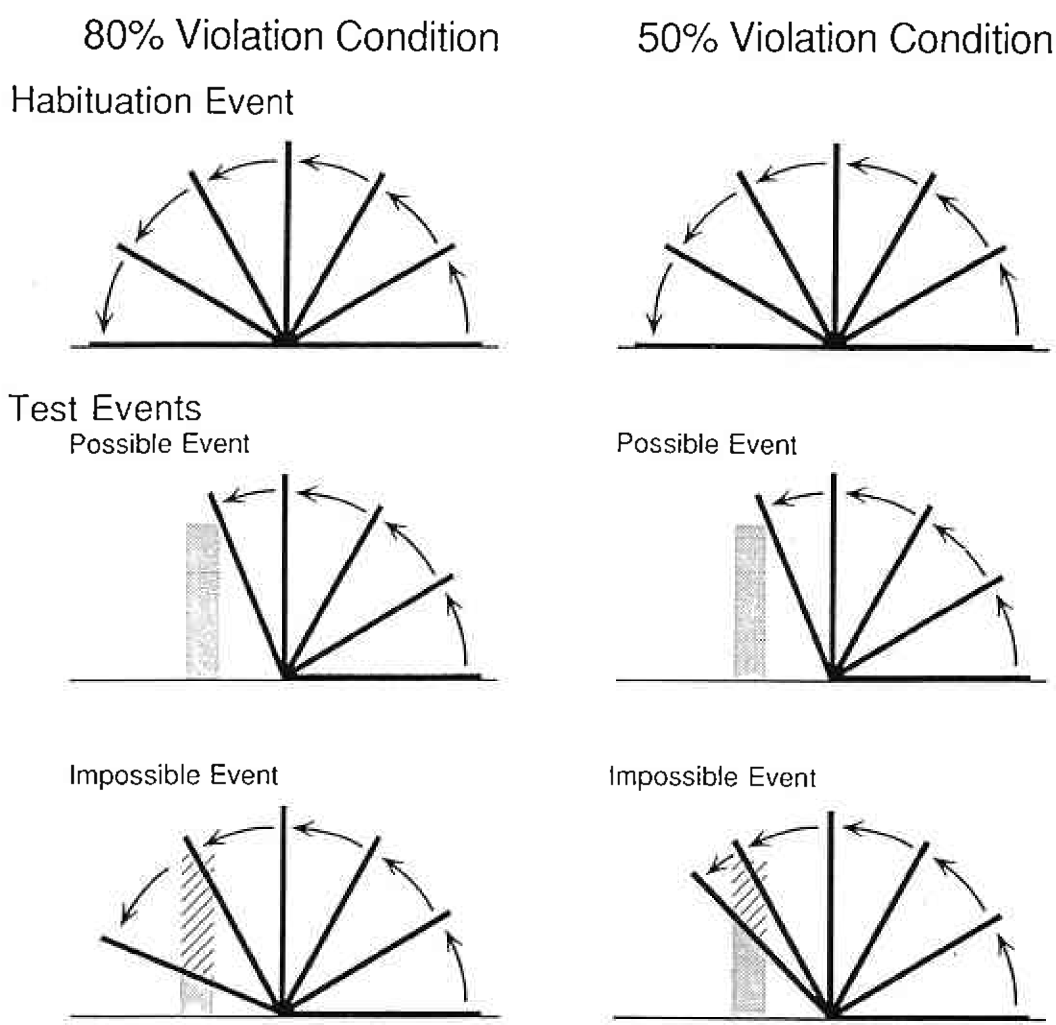

FIG. 9.5. Schematic drawing of the events shown to the infants in Baillargeon (1991, Exp. 1).

the 50% violation condition tended to look equally at the two test events. These results suggested that the infants were able to detect the 80% but not the 50% violation. A control condition conducted without a box behind the screen provided evidence that the infants in the 80% violation condition looked longer at the impossible event, not because they preferred the 157° rotation to the 112° rotation, but because they detected that the screen rotated farther than it should have given the box's height and location.

In a subsequent experiment, 4½-month-old infants were tested in the 80% violation condition. The infants failed to show a reliable preference for the impossible over the possible event, suggesting that, in contrast to the 6½-month-old infants, they were unable to detect the 80% violation.

The next experiments investigated whether infants would form more precise expectations about the screen's stopping point under different conditions. These experiments were identical to the last series with one exception: A second, identical box was placed 10 cm to the right of and in the same fronto-parallel plane as the box behind the screen (see Fig. 9.6). This second box stood out of the screen's path and so remained visible throughout the test trials.

With this second box present, (a) the 6½-month-old infants now looked reliably longer when the screen rotated through the top 50% of the occluded box, and (b) the 4½-month-old infants now looked reliably longer when the screen rotated through either the top 80% or the top 50% of the occluded box. These results suggested that the infants spontaneously made use of the second box to predict the screen's stopping point: They were able to detect with this box violations that they failed to detect without it. This interpretation was supported by control conditions in which the box behind the screen was removed, leaving only the box to the side of the screen. The infants in these control conditions tended to look equally at the different screen rotations. These findings provided evidence that the infants in the experimental conditions looked longer at the impossible events, not because they preferred the 157° or the 135° to the 112° screen rotation, but because they were surprised that the screen continued to rotate after it reached the occluded box.

How did the infants make use of the visible box to predict the screen's stopping point? At least two answers were possible. One was that the visible box facilitated the infants' *quantitative* reasoning by providing them with an exact reminder of the occluded box's height and distance from the screen. The other answer was that the visible box made it possible for the infants to offer a *qualitative* prediction about the screen's stopping point. That is, rather than computing the screen's approximate height at its stopping point, the infants could simply reason that the screen would stop when it was aligned with the top of the visible box. This prediction is said to be qualitative because it required no quantitative estimate of the screen's stopping point; the top of the visible box provided the infants with a direct reference point.

Did the infants in the experiments use the visible box to offer a quantitative or a qualitative prediction about the screen's stopping point? To decide between

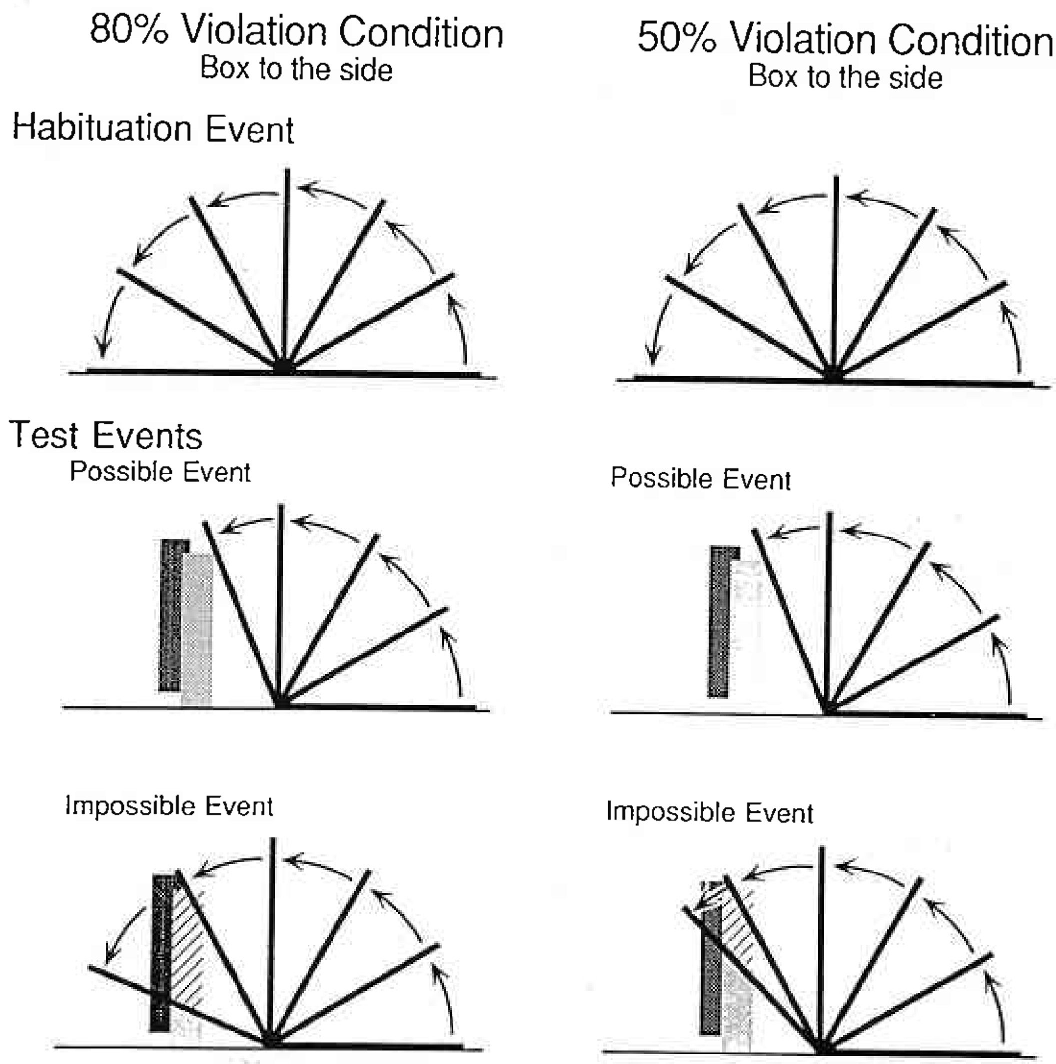

FIG. 9.6. Schematic drawing of the events shown to the infants in Baillargeon (1991, Exp. 4).

these two possibilities, experiments were conducted that were identical to the two-box experiments just described except that the visible box was no longer in the same fronto-parallel plane as the box behind the screen. The visible box now stood 10 cm to the right and 8.5 cm in front of the box behind the screen. Under these conditions, the infants still had a reminder of the occluded box's height and approximate distance from the screen, but they could no longer use an alignment strategy: The screen rotated past the top of the visible box in both the possible and the impossible events. The results indicated that (a) the 6½-month-old infants were no longer able to detect the 50% screen violation, and (b) the 4½-month-old infants were no longer able to detect the 80% and the 50% screen violations.

Together, the results of the experiments reported in this section revealed an interesting developmental sequence. At 6½ months of age, the infants were able to predict both quantitatively and qualitatively at what point the screen would reach the occluded box and stop. Quantitative predictions were produced when only the box behind the screen was present; qualitative predictions were produced when the second box was placed to the right of and in the same plane as the box behind the screen. Not surprisingly, the infants' quantitative predictions were less precise than their qualitative counterparts: The infants could detect 80% violations when reasoning quantitatively, and smaller, 50% violations when reasoning qualitatively.

At 4½ months of age, however, the infants were unable to predict quantitatively at what point the screen would stop. When only the box behind the screen was present, the infants detected 100% violations (Baillargeon, 1987a) but not 80% or 50% violations. They could reason *that* the screen should stop, and were surprised if it completed its 180° rotation without doing so; but they were unable to predict *at what point* the screen should stop.[2] The 112°, 135°, and 157° stopping points were all judged to be consistent with the box's height and location. When the second box was placed to the right of and in the same plane as the occluded box, however, the infants had no difficulty predicting qualitatively at what point the screen would stop, and now viewed both the 135° and the 157° stopping points as unacceptable.

Further Developmental Evidence. The experiments described in the last section pointed to important developments in infants' quantitative reasoning. Additional experiments indicated that there might be differences in infants' qualitative reasoning as well. These experiments tested whether 4½- and 6½-month-old infants would still be able to make use of the second box to detect 50% violations if it differed in appearance from the box behind the screen (Baillargeon, 1992). Technically, the superficial similarity of the two boxes is, of course, irrelevant: As long as the boxes are of the same height and are placed in the same plane, one can be used as a reference point for the other.

The infants were assigned to one of three conditions (see Fig. 9.7). The infants in the high-similarity condition saw two red boxes, one decorated with green dots and the other with white dots; the infants in the moderate-similarity

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[2] An alternative interpretation might be that, like the 6½-month-old infants, the 4½-month-old infants could predict both quantitatively and qualitatively at what point the screen should stop, but that their quantitative reasoning was so poor that it enabled them to detect only the 100% violation. Recall that the screen rotated through all 25 cm of the box in the 100% violation, and through the top 20 cm and 12.5 cm of the box in the 80% and the 50% violation, respectively. Thus, one might propose that infants can initially detect only extreme (25 cm or greater) violations, and gradually improve with age. However, some additional data are inconsistent with this view. In an unpublished experiment, 4½-month-old infants were found to detect a 100% violation in which a box only 12.5 cm high stood behind the screen. Similar results were obtained with 3½-month-old fast habituators (Baillargeon, 1987a). Such findings suggest that young infants use a qualitative strategy to detect 100% violations. Specifically, infants take as their point of reference the apparatus floor and reason that if the screen rotates until it lies flat against the floor, then it rotates farther than it should, given the presence of the box in its path.

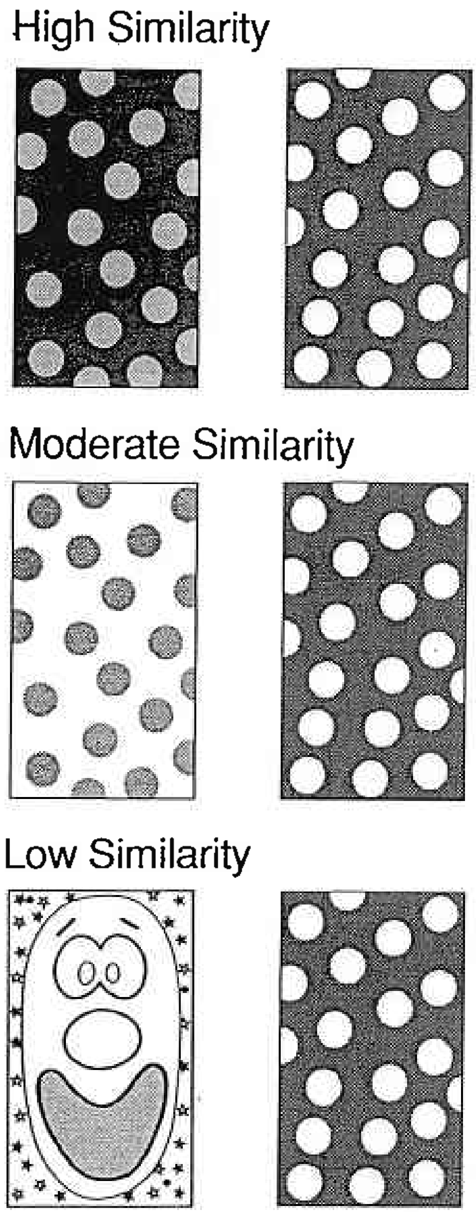

FIG. 9.7. Schematic drawing of the boxes shown to the infants in Baillargeon (1992).

condition saw a yellow box with green dots and a red box with white dots; the infants in the low-similarity condition saw a yellow box decorated with a brightly-colored clown face and a red box with white dots (boxes decorated with clown faces were used in all of the rotating screen experiments mentioned in the previous section). The results indicated that (a) the 6½-month-old infants detected the 50% violation in the high- and the moderate- but not the low-similarity condition and (b) the 4½-month-old infants detected the 50% violation in the high- but not the moderate- or the low-similarity conditions.

One possible interpretation for these findings was simply that, as the differences between the boxes increased, the infants became absorbed in the task of comparing the two boxes and as a result paid little or no attention to the screen's motion. To address this possibility, an additional group of 6½-month-old infants was tested using the low-similarity condition procedure. For these infants, however, the two boxes stood on either side of the screen throughout the habituation trials. The reasoning was that this prolonged exposure (the infants received a minimum of six and a maximum of nine habituation trials) would give the infants ample opportunity to peruse the two boxes. However, the results of the experiment were again negative: Despite their increased familiarity with the two boxes, the infants still failed to detect the 50% violation.

Two conclusions followed from the results of these experiments. One was that whether the infants used the visible box to predict when the screen would reach the occluded box depended on the perceptual similarity of the two boxes. The other conclusion was that the older the infants the less similarity they needed to make spontaneous use of the visible box. Whereas the 4½-month-old infants used the visible box to predict the screen's stopping point only when it was identical or highly similar to the occluded box, the 6½-month-old infants used the visible box even when it was only moderately similar to the occluded box. These results suggested that, with age, infants become better at dismissing irrelevant differences in objects they use as reference points in solving physical problems. One noteworthy aspect of these results is that they mirror findings from the analogical reasoning literature: Investigators have shown that children and adults are most likely to realize that the solution to a familiar problem may be of help in solving a novel problem when the superficial similarity between the two problems is high (Brown, 1989; D. Gentner & Toupin, 1986; Gick & Holyoak, 1980; Holyoak, Junn, & Billman, 1984; Ross, 1984).

Converging Evidence. The last set of experiments described in this section used a different paradigm than the rotating screen paradigm to gather converging evidence of young infants' ability to represent and to reason about the properties of occluded objects.

The experiments examined the ability of 5½-month-olds (Baillargeon & Graber, 1987) and 3½-month-olds (Baillargeon & DeVos, 1991) to represent and to reason about the height and trajectory of occluded objects. The infants were habituated to an object, such as a toy rabbit, that slid back and forth along a horizontal track whose center was hidden by a screen (see Fig. 9.8). On alternate trials, the infants saw a short or a tall rabbit slide along the track. Following habituation, the midsection of the screen's upper half was removed, creating a large window. The infants saw a possible and an impossible test event. In the possible event, the short rabbit moved back and forth along the track; this rabbit was shorter than the window's lower edge and thus did not appear in the window when passing behind the screen. In the impossible event, the tall rabbit moved back and forth along the track; this rabbit was taller than the window's lower edge and hence should have appeared in the window but did not in fact do so.

The infants looked equally at the short and the tall rabbit habituation events but looked reliably longer at the impossible than at the possible test event, sug-

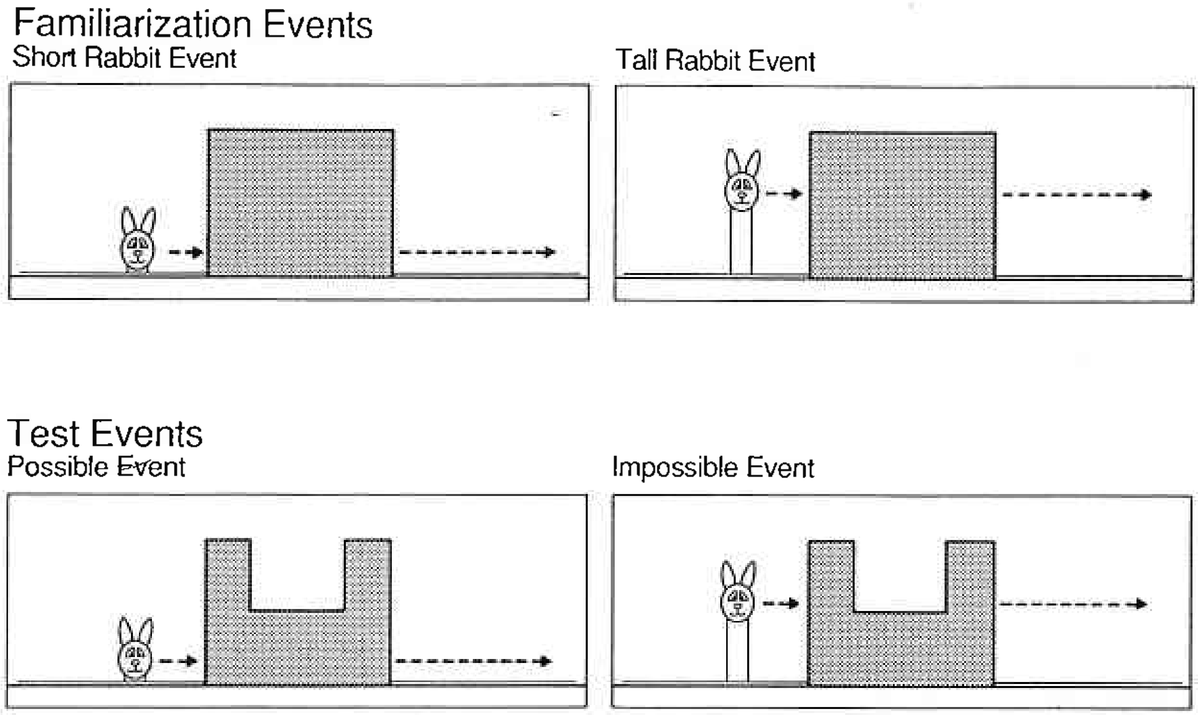

FIG. 9.8. Schematic drawing of the events shown to the infants in Baillargeon and Graber (1987).

gesting that they (a) represented the height of each rabbit behind the screen; (b) assumed that each rabbit pursued its trajectory behind the screen; and hence (c) expected the tall rabbit to appear in the screen window and were surprised that it did not. This interpretation was supported by the results of another condition that was identical to the experimental condition with one important exception: Prior to the habituation trials, the infants received two pretest trials in which they saw two short or two tall rabbits standing motionless, one on each side of the windowless habituation screen. Half of the infants saw the two short rabbits in the first trial and the two tall rabbits in the second trial; the other infants saw the rabbits in the opposite order. Unlike the infants in the experimental condition, the infants in this pretest condition looked equally at the impossible and the possible events. One explanation for these results was that the infants were able to use the information presented in the pretest trials to make sense of the impossible event. Specifically, the infants understood that the tall rabbit did not appear in the screen window because it did not in fact travel the distance behind the screen: Instead, one rabbit traveled from the left end of the track to the left edge of the screen and stopped just inside this edge; a second, identical rabbit then emerged from the right edge of the screen and traveled to the right end of the track (see Baillargeon & DeVos, 1991, for a fuller discussion of these results).

How did the infants in the experimental condition determine whether the tall or the short rabbit should appear in the screen window? The most likely answer, we believed, was that the infants visually compared the height of each rabbit, as it approached the screen, to that of the window. Such a direct visual comparison process was of course qualitative, because it did not require the infants to compute estimates of how high each rabbit would extend above the window's lower edge. This account is analogous to that offered in the last section to explain infants' performances in the two-box experiments.

Three conclusions followed from the present results. First, they confirmed the finding, reported earlier, that 3½-month-old infants represent the existence of occluded objects (Baillargeon, 1987a). Second, the results indicated that infants this age are also able to represent and to reason about some of the physical (height) and spatial (trajectory, location) properties of occluded objects. This finding provided evidence against the hypothesis that the object concept develops in stages, with infants representing first the existence and only later the properties of occluded objects. Finally, the absence of significant differences (Baillargeon & DeVos, 1991) between the responses of the 3½-month-old fast and slow habituators in the experimental condition indicated that both groups of habituators believed that objects continue to exist when out of sight. This finding ruled out one interpretation of the differences obtained in Baillargeon's (1987a) rotating screen experiment, namely, that only the fast habituators preferred the impossible event because only they had attained a notion of object permanence.

Inferring the Existence and Properties of Occluded Objects

The results reported in the last section indicated that infants represent the properties of occluded objects long before the age of 12 months. This finding suggested that infants might be able to make inferences about occluded objects—the last step in Piaget's (1954) developmental sequence—before 18 months of age. The experiments presented in this section examined infants' ability to infer the existence and the properties of occluded objects.

Existence. The first experiment in this series tested 6- and 9-month-old infants' ability to infer the presence of a hidden object from the presence of a protuberance in a soft cloth cover (Baillargeon & DeVos, 1992). The infants were shown a possible and an impossible event (see Fig. 9.9). At the start of each event, the infants saw two covers made of soft pink fabric; one lay flat on the table, and the other showed a large protuberance. Next, two screens were pushed in front of the covers, hiding them from view. A hand then reached behind the right screen and reappeared first with the cover and then with a toy bear of the same height as the protuberance seen earlier. The only difference between the two test events was in the location of the two covers at the start

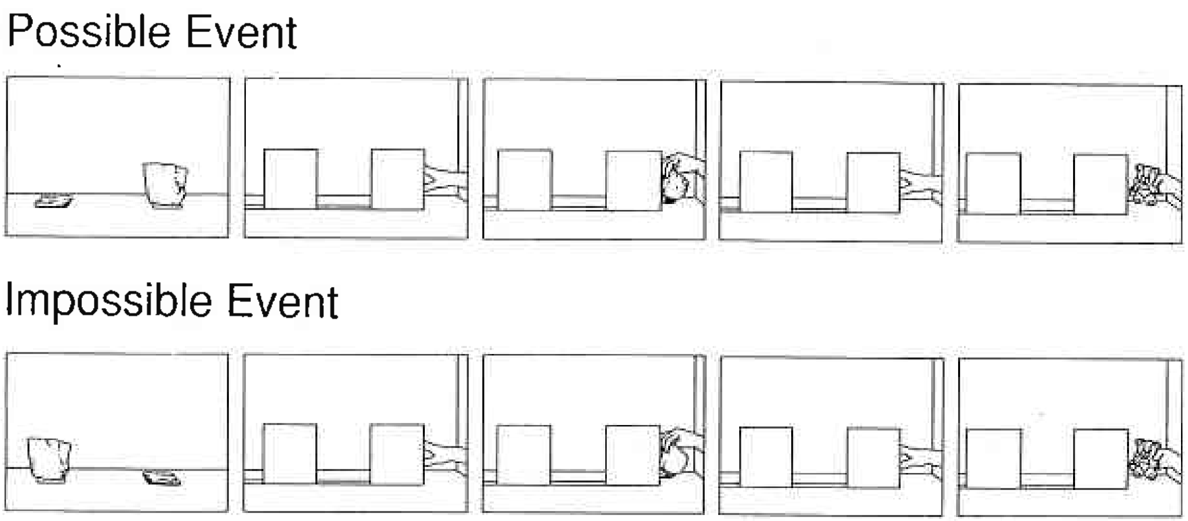

FIG. 9.9. Schematic drawing of the events shown to the infants in Baillargeon and DeVos (1992, Exp. 1).

of the trials. In the possible event, the flat cover was behind the left screen and the cover with the protuberance was behind the right screen; in the impossible event, the position of the two covers was reversed.

The results indicated that the 9-month-old infants looked reliably longer at the impossible event, suggesting that they (a) represented the appearance and location of the two covers behind the screens and (b) understood that an object could be retrieved from under the cover with a protuberance but not the flat cover. This interpretation was supported by a control condition in which the hand reached behind the left rather than the right screen so that the bear's position in the impossible and the possible events was reversed.[3]

In contrast to the 9-month-old infants, the 6-month-old infants looked equally at the impossible and the possible events, suggesting that they found it equally plausible for the bear to have been hidden under the cover with a protuberance or the flat cover. This negative result was replicated in another experiment conducted with a simpler procedure. In this experiment, the infants saw a single cover in each test event: the flat cover in the impossible event, and the cover with a protuberance in the possible event. After a few seconds, the cover was hidden by a screen. Next, the hand reached behind the screen and retrieved first the cover and then the toy bear. The infants again looked equally at the impossible and the possible events, suggesting that they believed that the bear could have been hidden under either the flat cover or the cover with a protuberance.

[3]These results have implications for explaining infants' perseverative search errors. Piaget (1954), Bower (1974), and others have noted that infants will return to a location, A, for an object they have seen disappear in a location B, *even when* the object creates a large protuberance or emits a sound under the B cover. The present results suggest that by 9 months of age infants have the cognitive ability to use such information to infer where the object is hidden. Why infants do not make this inference is addressed further on.

These negative results seemed inconsistent with the results of the first rotating screen task described earlier (Baillargeon, 1987a). In this task, 5½-, 4½-, and even 3½-month-old infants were surprised to see the screen lay flat against the apparatus floor when the box stood behind it. In the present task, 6-month-old infants were *not* surprised to see the bear retrieved from under a cover that lay flat against the apparatus floor. Both tasks called upon the same general physical knowledge: In each case, the infants had to appreciate that objects continue to exist when hidden, and that objects cannot occupy the same space as other objects. Nevertheless, there was one important difference between the two tasks. In the rotating screen task, the infants saw the box and then were asked to predict its effect on the screen. In the present task, however, the infants did not see the bear but had to infer its presence from its effect on the cover. What this analysis suggests is that infants are able to reason about known objects several months before they are able to make inferences about unknown objects. Having formed a representation of an object, infants can use this representation to reason about the object after it has become hidden from view. However, infants cannot make inferences about an unknown object, even when the cues that point to the existence of the object call upon precisely the same knowledge infants would use to reason about a known object. We return to this issue at the end of the next section.

Size. The results described in the last section indicated that, by 9 months of age, infants could use the presence of a protuberance in a soft cloth cover to infer the existence of an object beneath the cover. Our next experiment investigated whether infants could also use the size of a protuberance in a cloth cover to infer the size of the object beneath the cover (Baillargeon & DeVos, 1992).

In this experiment, 12½- and 13½-month-old infants watched two test events (see Fig. 9.10). At the start of each event, the infants saw a purple cloth cover with a protuberance approximately equal in size to that in the last experiment. Next, a screen was raised in front of the cover, hiding it from view. A hand then reached behind the screen twice in succession, reappearing first with the cover and then with either a small dog of the same size as the protuberance (possible event), or a large dog more than twice as large as the protuberance (impossible event).

The 13½-month-old infants looked reliably longer at the impossible than at the possible event, suggesting that they (a) used the size of the protuberance in the cover to infer the size of the object under the cover, and hence (b) were surprised to see the hand reappear holding the large dog. Support for this interpretation came from a control condition in which a cover with a protuberance as large as the large dog was shown at the beginning of the test events. The infants in this condition looked about equally when the large and the small dogs were retrieved from behind the screen. This finding showed that the infants in the experimental condition looked reliably longer at the impossible event, not

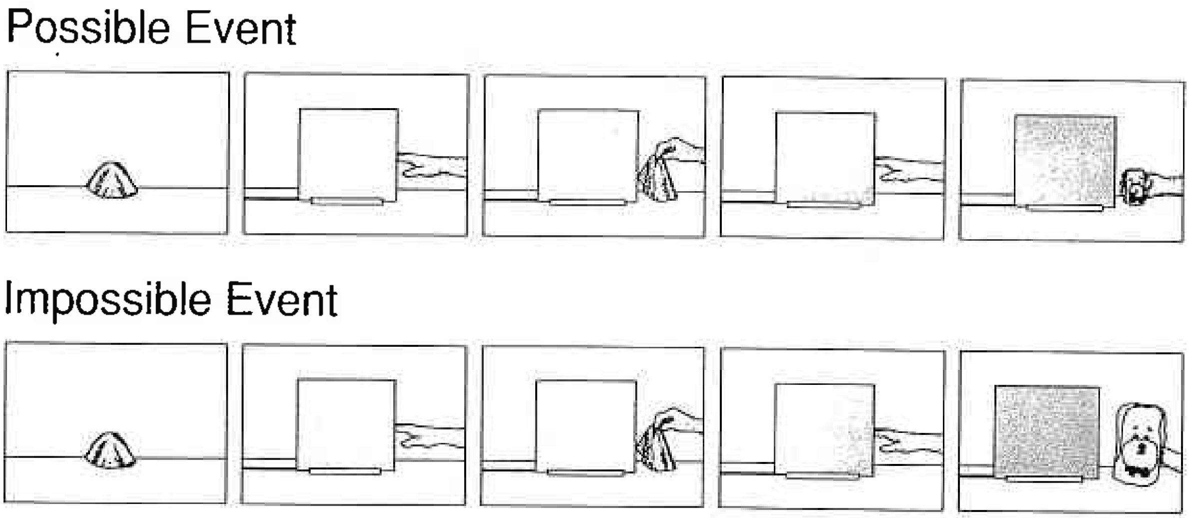

FIG. 9.10. Schematic drawing of the events shown to the infants in Baillargeon and DeVos (1992, Exp. 4).

because they preferred the large dog, but because they realized that its size was inconsistent with the size of the protuberance shown at the start of the event.

Why did the infants in the control condition look equally when the small and the large dogs were retrieved from under the cover? The most likely explanation, we believed, was that the infants realized that neither event was impossible: Either dog could have been hidden under the cover. Something in addition to the small dog could have been hidden under the cover, such as a doghouse, to give the cover its large protuberance.

In contrast to the 13½-month-old infants, the 12½-month-old infants (in the experimental condition) tended to look equally at the impossible and the possible events, suggesting that they believed that the large or the small dog could have been hidden under the cover. Our next experiment examined whether infants would perform better when provided, as in the two-box rotating screen experiments described earlier (Baillargeon, 1991), with a second, identical cover that remained visible throughout the experiment (see Figure 9.11). Subjects in the experiment were 12½- and 9½-month-old infants.

The 9½-month-old infants tended to look equally at the two test events. In contrast, the 12½-month-old infants looked reliably longer at the impossible than at the possible event, suggesting that they made use of the visible cover to judge that the small but not the large dog could have been hidden under the cover behind the screen. A control condition supported this interpretation. The infants in this condition were simply shown the hand holding the small or the large dog next to the visible cover, as in the right panels in Fig. 9.11. The infants in this condition looked about equally at the large and the small dog displays. This result provided evidence that the infants in the experimental condition looked longer at the impossible event, not because they preferred seeing the large dog next to the visible cover, but because they detected that this dog was too large to have been hidden under the cover behind the screen.

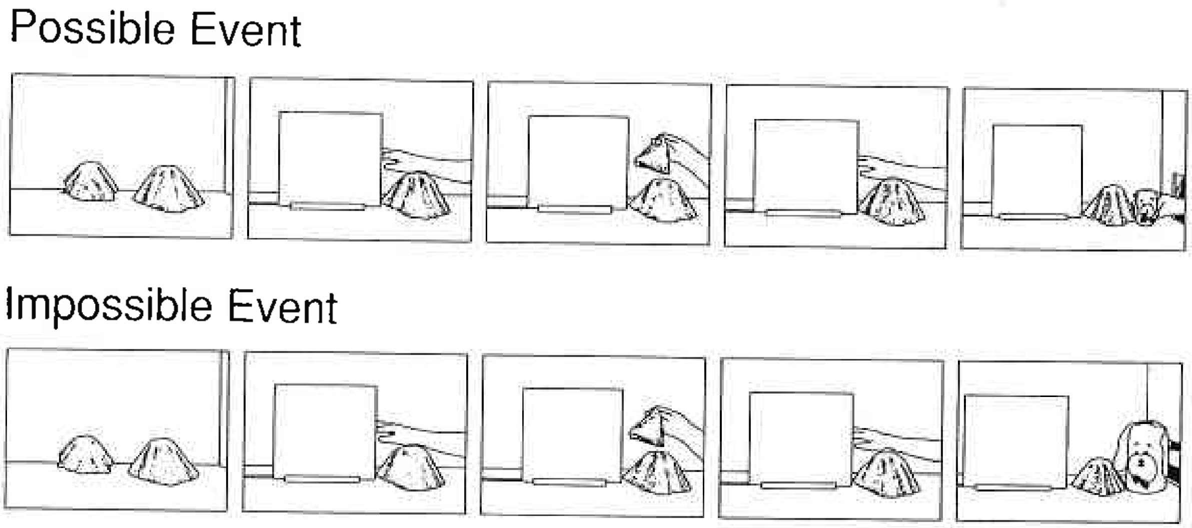

FIG. 9.11. Schematic drawing of the events shown to the infants in Baillargeon and DeVos (1992, Exp. 5).

The 12½-month-old infants in this last experiment clearly made use of the visible cover to determine which dog could have been hidden under the cover behind the screen: They were able to detect, with the help of this second cover, a violation that they failed to detect without it. How did the second cover help the infants' performance? As in the two-box experiments described earlier (Baillargeon, 1991), two answers were possible. One was that the second cover enhanced the infants' quantitative reasoning by providing them with an exact reminder of the size of the hidden cover's protuberance. Armed with this reminder, the infants were then in a better position to compute a quantitative estimate of the size of the object hidden under the cover. The other possibility was that the visible cover enabled the infants to use a qualitative approach to judging which dog could have been hidden under the cover behind the screen, by comparing each dog to the visible cover.

To decide between these two possibilities, an additional group of 12½-month-old infants was tested in a control condition in which the visible cover was placed to the left rather than to the right of the screen. In this condition, the infants still had a reminder of the hidden cover's exact size, but because the dog was retrieved to the right of the screen they could no longer compare in a single glance the visible cover and the small or the large dog. The infants in this condition looked about equally at the two events. This finding provided evidence that the infants in the experimental condition detected that the large dog could not have been hidden under the cover behind the screen by directly comparing the size of the visible cover to that of the small and the large dogs.

The results of these experiments were in many ways strikingly similar to those of the rotating screen experiments discussed earlier (Baillargeon, 1991). Recall that the 6½-month-old infants could predict quantitatively, but the 4½-month-old infants only qualitatively, at what point the screen would reach the occluded box and stop. Similarly, in the present experiments, the 13½-month-old infants could reason quantitatively, but the 12½-month-old infants only qualitatively, about the size of the dog hidden beneath the cover behind the screen.

One explanation for these results is that, as infants become aware of specific variables affecting events' outcomes (e.g., the height and location of the box in the rotating screen task, or the size of the protuberance in the soft cover task), they are able to reason at first qualitatively and only later quantitatively about the effect of these variables. Why development should proceed in this manner is as yet unclear. However, the answer is unlikely to involve infants' memory for quantitative information. Recall that the infants in the rotating screen experiments failed to detect the 50% violation when the visible box was moved slightly forward of the hidden box, just as the 12½-month-old infants in the present experiments failed to realize that the large dog could not have been under the hidden cover when the visible cover was placed to the left of the screen. Providing the infants with a reminder of the hidden object's size and location thus did not improve their performance, suggesting that a faulty memory was not the primary source of their difficulty.

Despite their similarity, the results of the experiments reported in this section differ from the results of the rotating screen experiments in one crucial respect: They involve much older infants. The décalages revealed by these experiments parallel the one discussed in the last section. Recall that infants were found to be able to reason about the existence of a known, hidden object several months before they were able to infer the existence of an unknown hidden object. The present results suggest that infants are also able to reason (qualitatively and quantitatively) about the properties of a known hidden object long before they can infer (qualitatively and quantitatively) the properties of an unknown hidden object. Why are infants very good, from an early age, at reasoning about what they know, but very poor, until late in the first year, at inferring what they don't know? We return to this question in the Conclusion.

Location. Piaget (1954) held that infants less than 18 months of age are unable to infer the location of hidden objects because they are unable to infer displacements that occur behind occluders. We have recently begun experiments to examine this claim with infants aged 11½ to 13½ months. These experiments are too preliminary to be described here. The initial results we have obtained, however, tentatively suggest that by the end of the first year infants are already able to infer a hidden object's location. If valid, these results would indicate that Piaget underestimated the age at which infants begin to show evidence of this ability. In addition, the results would again point to a marked décalage between infants' ability to reason about locations and trajectories they have directly witnessed, even after these are hidden from view, and to infer novel locations and trajectories. Recall that in the rolling car experiments reported earlier, 8-, 6½-, and even 4-month-old infants were able to reason about the location of the box and the trajectory of the car behind the screen (Baillargeon, 1986; Baillargeon & DeVos, 1991). Similarly, in the sliding rabbits experiments, 5½- and 3½-month-old infants were able to reason about each rabbit's trajectory behind the screen (Baillargeon & Graber, 1987; Baillargeon & DeVos, 1991).

Piaget assumed that because young infants could not infer invisible displacements, they did not appreciate that occluded objects obey the same physical laws as visible objects. Although Piaget may have been right in claiming that young infants cannot infer hidden trajectories, there is reason to doubt that young infants do not understand that occluded objects follow the same predictable patterns as visible objects. The infants in the car and the sliding rabbits experiments clearly perceived the car's and the rabbits' displacements behind the screen to be constrained by the same laws that apply to visible displacements. In particular, the infants believed that the car and the rabbits moved along continuous paths behind the screen just as they did on either side of the screen; they understood that the car could not roll through the box in its path; and they assumed that each rabbit retained its height while traveling behind the screen. Such data support the notion that young infants' inability to make inferences about hidden objects stems not from a belief that hidden objects' displacements and interactions with other objects are arbitrary and unpredictable, but from an incapacity to reason without concrete representations of objects and their properties.

WHY THE DISCREPANCY BETWEEN SEARCH AND NON-SEARCH ASSESSMENTS OF OBJECT PERMANENCE?

The experiments reported earlier indicated that infants represent the existence and the location of hidden objects at a very early age. Why, then, do infants fail to search for hidden objects until 7½ to 9 months of age? And why do they search perseveratively when they begin to search for objects? These two questions are considered in turn.

Why do Young Infants Fail to Search for Hidden Objects?

If infants realize, at 3½ months of age, that objects continue to exist when hidden, why do they fail to search for objects until 7½ to 9 months of age (e.g., Diamond, 1985; Willatts, 1984)? It is not surprising that 3½-month-old infants, whose motor abilities are very limited, do not engage in search activities, but what of older infants? Why do they fail to search for hidden objects?

One possibility is suggested by observations on the development of action in infancy. Researchers (e.g., Diamond, 1988; Piaget, 1952; Willatts, 1989) have noted that it is not until infants are 7½ to 9 months of age that they begin to coordinate actions directed at separate objects into means–end sequences. In these sequences, infants apply one action to one object so as to create conditions under which they can apply another action to another object. Examples of such sequences include pulling the near end of a cloth to bring within reach a toy placed on the far end of the cloth, pushing aside a cushion to get a toy visible on the other side of the cushion, or reaching around to the opening of a transparent box to get a toy placed inside the box. Thus, young infants might fail to search for hidden objects simply because this task typically requires them to coordinate separate actions on separate objects (e.g., lifting a cloth to get a toy hidden under the cloth).

Support for this hypothesis comes from reports that infants *do* search for hidden objects when they can find the objects by performing direct, as opposed to means–end, actions. First, a number of authors (e.g., Bower & Wishart, 1972; Clifton, Rochat, Litovsky, & Perris, 1991; Hood & Willatts, 1986) have found that young infants readily search for objects "hidden" by darkening the room. For example, Hood and Willatts (1986) presented 5-month-old infants with an object on the left or the right side within reaching distance; the infants were restrained from reaching for the object. Next, the room lights were turned off, the object was removed, and the infants' hands were released. Infrared recordings indicated that the infants reached more often to the side where they had seen the object than to the opposite side.

Second, recall Piaget's observation that when young infants hold an object out of sight and accidentally let go of it, they often stretch their arm to recapture it. One of Piaget's protocols involved his son Laurent: "As early as 0;4(6) Laurent searches with his hand for a doll he has just let go. He does not look at what he is doing but extends his arm in the direction toward which it was oriented when the object fell" (Piaget, 1954, p. 23).

Finally, young infants search visually for objects, as when they anticipate objects' reappearance from behind occluders (e.g., Moore, Borton, & Darby, 1978; Piaget, 1954). In a similar vein, we have observed that infants who are shown impossible events involving an object hidden behind a screen sometimes lean to the side and attempt to look behind the screen, as if to verify for themselves the continued presence of the object.

Thus, it appears that young infants do search for hidden objects when they can search without producing means–end sequences, by groping for objects "hidden" by the dark or dropped out of sight, or by peering past or around screens that block their line of vision.

On the strength of this evidence, let us assume that young infants perform poorly on most search tasks because these tasks typically require them to produce means–end sequences. The next question we must address is: Why do infants less than 7½ to 9 months of age have difficulty producing means–end sequences? Two general hypotheses come to mind. One is that infants are unable to *perform* such sequences because of poor motor control; the other is that infants are unable to *plan* such sequences because of limited problem solving ability.

Studies of young infants' actions provide little support for the first hypothesis. The actions involved in the examples of means–end sequences I have listed (reaching for, grasping, pulling, pushing, lifting, and releasing objects) fall well within the behavioral repertoire of 4- to 7-month-old infants (Bushnell, 1985; Granrud, 1986; von Hofsten, 1980; Newell, Scully, McDonald, & Baillargeon, 1989; Piaget, 1952, 1954). Furthermore, infants this age seem to have little difficulty performing series of actions in rapid succession. Piaget (1952) described in meticulous and delightful detail how his children, beginning at 3½ months of age, would repeatedly kick, pull, swing, shake, or strike objects suspended from their bassinet hoods, at times systematically varying the speed and vigor of their actions, and at other times playfully intermingling bouts of different actions, such as pulling and shaking or striking and shaking. Such observations are inconsistent with the hypothesis that young infants' failure to produce means–end sequences stems from inadequate motor skills.

The second hypothesis was that young infants are unable to plan means–end sequences because of problem solving difficulties. Before discussing the potential source of these difficulties, let us define a few terms.

Problem solving is frequently described in cognitive psychology in terms of searching a *problem space*, which consists of various states of a problem. The goal pursued by the problem solver is referred to as the *goal state* and the initial situation that faces the problem solver as the *initial state; operators* are actions carried out by the problem solver to generate each successive *intermediate state* on the way to the goal (e.g., Anderson, 1985; Mayer, 1983; Newell & Simon, 1972).

Having established this terminology, we can now consider a typical search problem situation: A young infant watches an experimenter hide an attractive toy under a cover. To what should we attribute the infant's failure to search for the toy? A first possibility is that the infant's goal in the situation differs from what the experimenter has in mind. Instead of seeking to retrieve the toy, the infant may be pursuing a different, unrelated goal. A second possibility is that the infant's representation of the situations' initial state is inaccurate or incomplete, making it impossible for the infant to find a sequence of operators to retrieve the toy. For example, the infant may represent the existence but not the location of the hidden toy.

Neither of these two possibilities is likely, however. With respect to the first possibility, there is ample evidence that young infants reach readily for objects that are "hidden" by the dark (Clifton et al., 1991; Hood & Willatts, 1986), as well as for objects that are only partially visible (Piaget, 1954). Furthermore, young infants are sometimes distressed when desired objects are hidden before them and attempt to grasp the objects as soon as they are even partially uncovered, either by the experimenter's or by their own chance actions (Piaget, 1954). Such observations are inconsistent with the hypothesis that young infants do not search for hidden objects because they have no wish to possess them. With respect to the second possibility, it is difficult, given the results of the experiments I have summarized (e.g., Baillargeon, 1986, 1987a, 1991; Baillargeon & DeVos, 1991; Baillargeon et al., 1985; Hood & Willatts, 1986), to believe that young infants' representation of the initial conditions of search situations could be seriously flawed. The results of these experiments suggest that young infants are able to represent the existence and the location of hidden objects and to reason about these objects in sophisticated, adult-like ways. Such findings are not easily reconciled with the proposal that young infants fail to retrieve objects hidden behind obstacles because their representation of the objects, the obstacles, or the relations between them is deficient.

Young infants' representation of the goal state and initial state of means–end problem situations thus seems unlikely to be responsible for their lack of success in these situations. Another, more likely possibility is that this lack of success reflects difficulties in reasoning about operators—about the actions that are applied to transform the initial state into the goal state. Two general hypotheses can be distinguished. First, it may be that infants perform poorly in means–end situations because their knowledge of the relevant operators is lacking or incomplete. Infants may not be fully aware of the preconditions necessary for the application of an operator, or of the effects of an operator. For example, infants may realize that grasping an object will result in their possession of the object, but not that it will *also* alter the location of the object relative to other objects in the situation. Infants would thus be unable to appreciate why grasping the cover placed over a toy would bring them closer to achieving their goal of recovering the toy; to their minds, grasping the cover would result only in their holding the cover, not in their gaining access to the toy. Second, it may be that infants are unable to select or chain appropriate sequences of operators to achieve their goals, even when the relevant operators and their preconditions and effects are well-known to them.

Experiments were conducted to examine the first of the two hypotheses just mentioned, namely, that young infants are unable to plan means–end search sequences because they lack sufficient knowledge about the operators or actions involved in the sequences (Baillargeon, Graber, DeVos, & Black, 1990). In these experiments, 5½-month-old infants were shown events in which a toy was placed in front of, behind, or under an obstacle. The experiments tested whether the infants could distinguish between actions (performed by an experimenter's hand) that *could* result in the toy's retrieval and actions that could *not*. We reasoned that evidence that the infants could identify correct and incorrect actions for the toy's retrieval would argue against the hypothesis that young infants cannot plan search sequences because their knowledge of the relevant actions is lacking or incomplete.

Our first experiment examined whether 5½-month-old infants are aware that a direct reaching action is sufficient to retrieve a toy placed in front of an obstacle, but is not sufficient to retrieve a toy placed behind (barrier condition) or under (cover condition) an obstacle.

The infants in the barrier condition were shown a possible and an impossible test event (see Fig. 9.12). At the start of each event, the infants saw a toy bird and a barrier standing side by side at the center of a display box. After a few seconds, a screen was pushed in front of the objects, hiding them from view. Next, a hand reached behind the screen's right edge and reappeared holding the bird. The only difference between the two events was in the relative positions of the bird and the barrier at the start of the events. In the possible event, the barrier was on the left and the bird was on the right, directly accessible to the hand; in the impossible event, the bird was on the left and the barrier was on the right, blocking the hand's access to the bird. Prior to the test events, the infants saw familiarization events designed to acquaint them with various facets of the events (see Fig. 9.12).

The events shown to the infants in the cover condition were similar to those

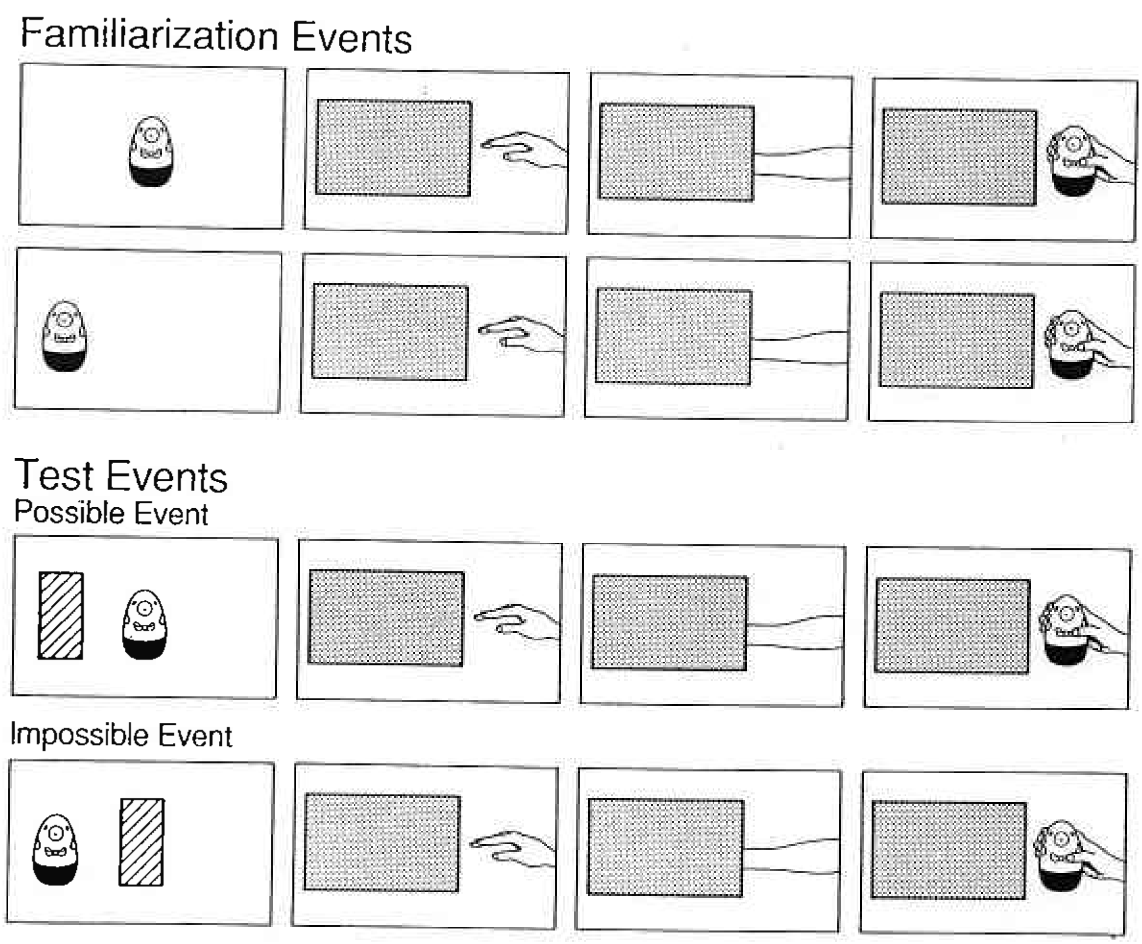

FIG. 9.12. Schematic drawing of the events shown to the infants in the barrier condition in Baillargeon et al. (1990, Exp. 1).

in the barrier condition except that the bird and the barrier were replaced by a bear and a clear rigid cover (see Fig. 9.13). In the possible event, the cover was on the left and the bear was on the right, where it could be retrieved by the hand; in the impossible event, the bear was under the cover and should therefore have been inaccessible to the hand.

The results indicated that the infants in the two conditions looked reliably longer at the impossible than at the possible event, suggesting that they (a) represented the existence and the location of the toy (bird, bear) and the obstacle (barrier, cover) behind the screen; (b) realized that the direct reaching action of the hand could result in the retrieval of the toy when it stood in front of, but not behind (barrier condition) or under (cover condition), the obstacle; and therefore (c) were surprised in the impossible event to see the hand reappear from behind the screen holding the toy. Support for this interpretation was provided by pretest trials which showed that the infants in the barrier condition did not prefer seeing the bird behind rather than in front of the barrier, and that the infants in the cover condition did not prefer seeing the bear under as opposed to in front of the cover.

The results of this experiment suggested that, by 5½ months of age, infants are aware that a direct reaching action is insufficient to retrieve an object placed behind or under an obstacle. Our next experiment examined whether

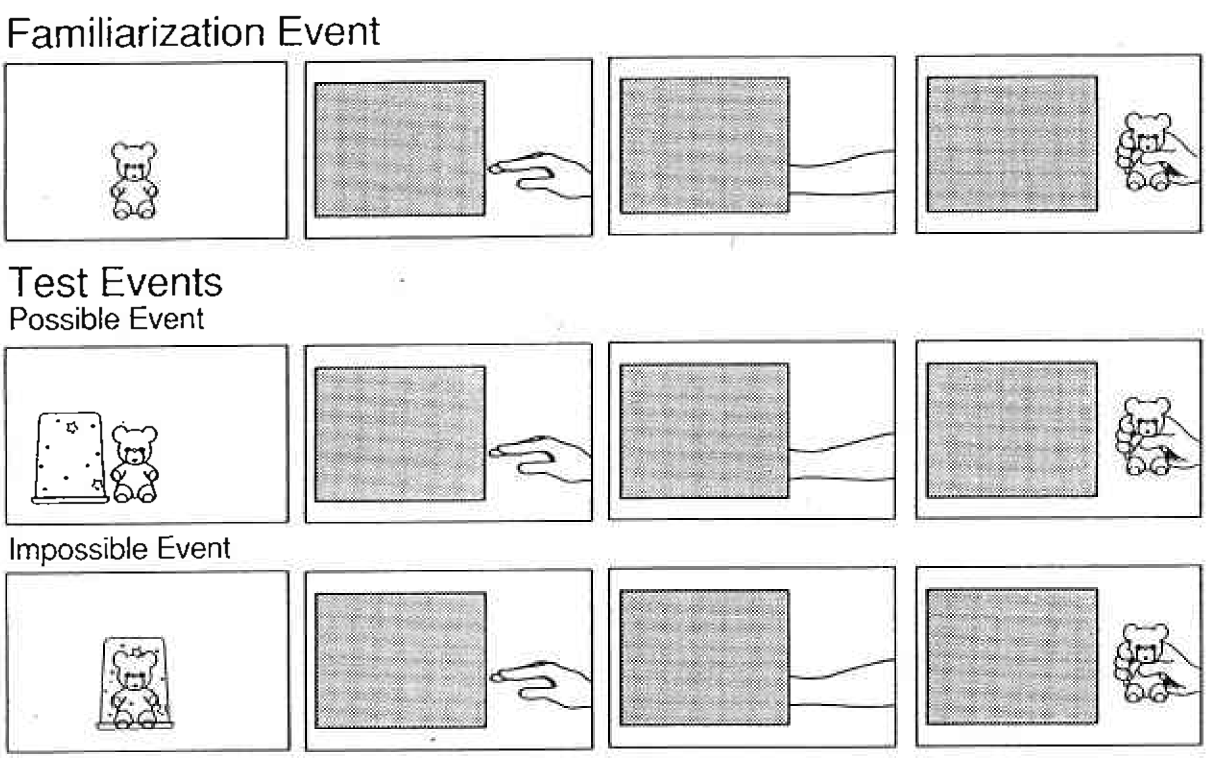

FIG. 9.13. Schematic drawing of the events shown to the infants in the cover condition in Baillargeon et al. (1990, Exp. 1).

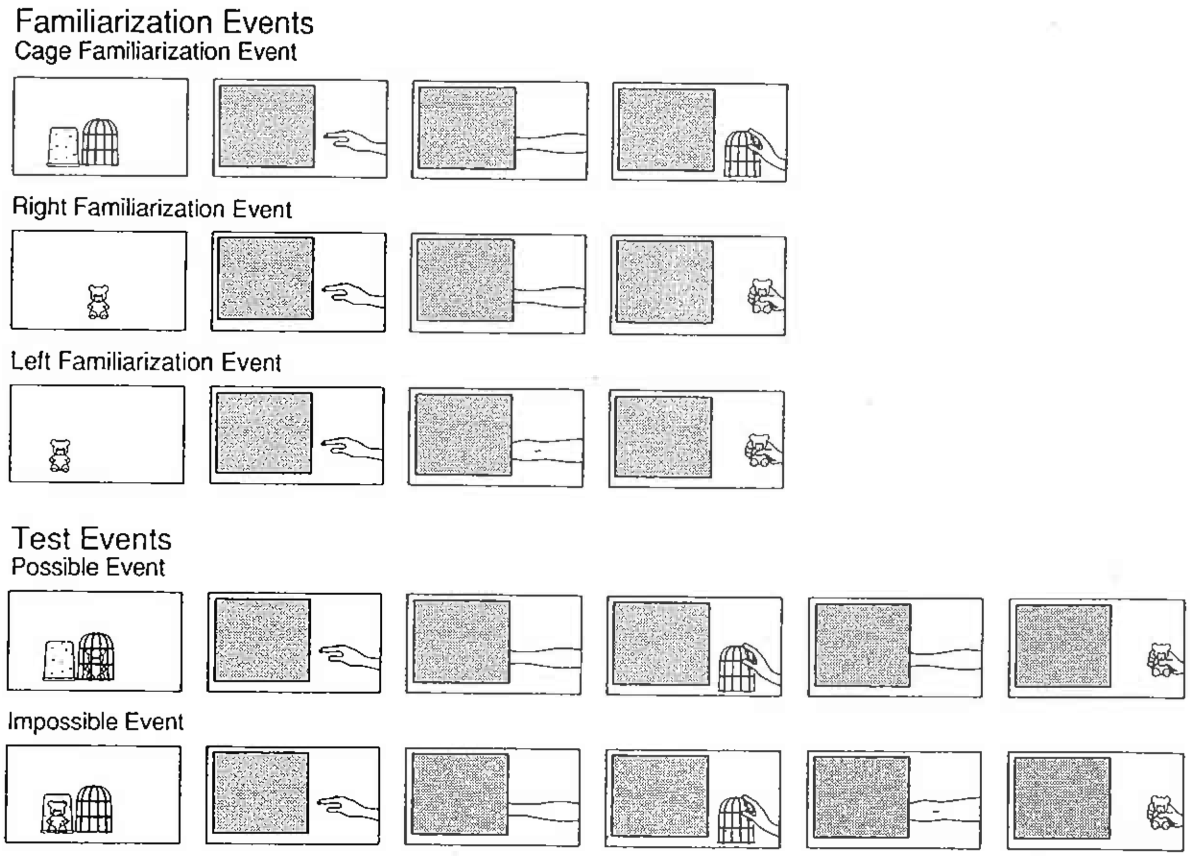

FIG. 9.14. Schematic drawing of the events shown to the infants in the experimental condition in Baillargeon et al. (1990, Exp. 2).

infants this age know what actions *are* sufficient to retrieve an object placed under an obstacle.

The infants again saw a possible and an impossible test event (see Fig. 9.14). At the start of each event, the infants saw two covers placed side by side: On the left was the clear cover used in the first experiment and on the right was a small cage. The toy bear used in the first experiment stood under one of the two covers. After a few seconds, a screen was pushed in front of the objects, hiding them from view. Next, a hand reached behind the screen's right edge and reappeared holding the cage. After depositing the cage on the floor of the apparatus, the hand again reached behind the screen and reappeared holding the bear. The only difference between the two test events was in the location of the bear at the start of the events. In the possible event, the bear was under the cage and hence could be retrieved after the cage was removed. In the impossible event, the bear was under the clear cover and hence should still have been inaccessible to the hand after the cage was removed. Prior to the test events, the infants saw familiarization events designed to acquaint them with different facets of the test situation.

A second group of 5½-month-old infants was tested in a control condition identical to the experimental condition except that the clear cover was replaced by a shallow, clear container. The bear's head and upper body protruded above the rim of the container (see Fig. 9.15). In this condition, the bear was always accessible to the hand after the cage was removed.

The infants in the experimental condition looked reliably longer in the impossible than at the possible event, whereas the infants in the control condition tended to look equally at the bear-in-container and the bear-in-cage events. These results indicated that the infants (a) represented the existence and the location of the bear, the cage, and the clear cover or container behind the screen; (b) understood that the hand's sequence of actions was sufficient to retrieve the bear when it stood under the cage or in the container but not when it was placed under the clear cover; and hence (c) were surprised in the impossible event when the hand reappeared holding the bear.

The results of these initial experiments indicated that young infants can readily identify what actions are and what actions are not sufficient to retrieve objects whose access is blocked by obstacles. Would young infants be as successful at reasoning about other means–end problems? To explore this question, we

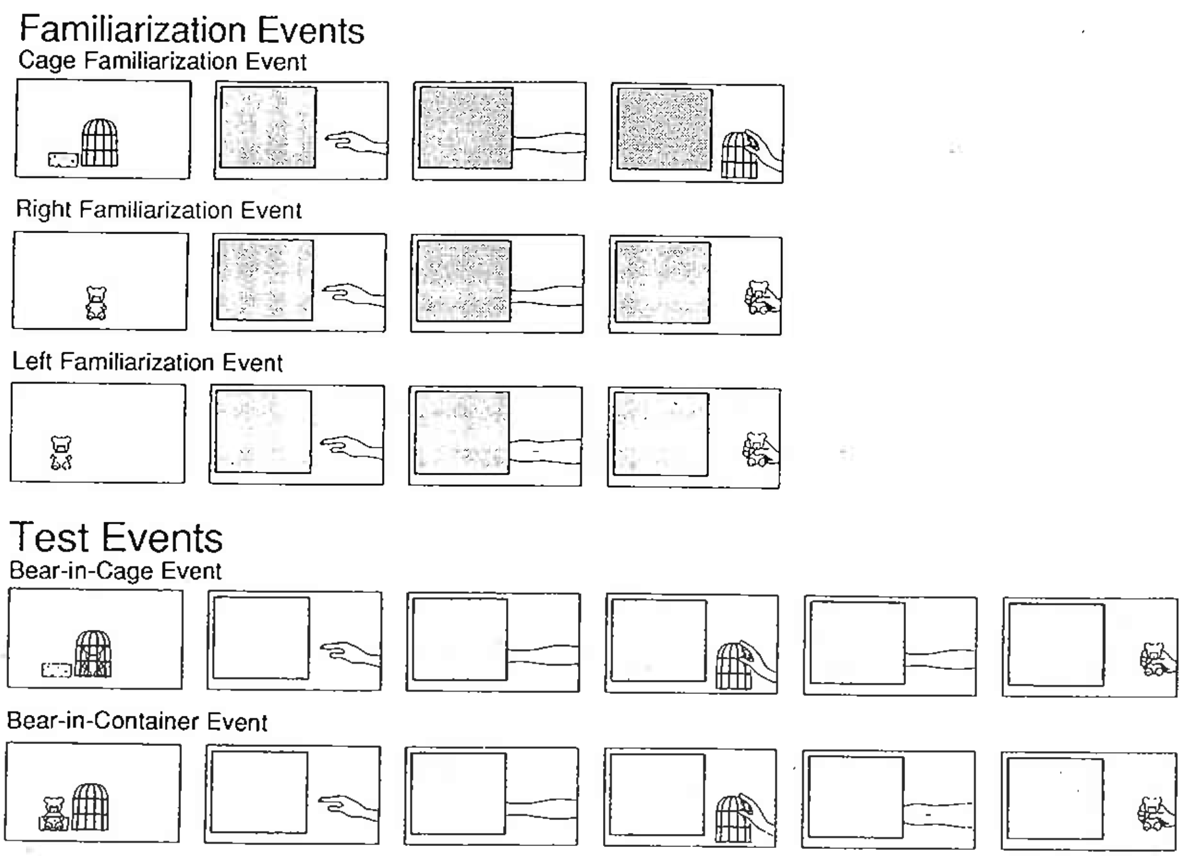

FIG. 9.15. Schematic drawing of the events shown to the infants in the control condition in Baillargeon et al. (1990, Exp. 2).

have begun experiments on another means–end sequence infants have been found not to produce until 7½ to 9 months of age, namely, pulling one end of a support to bring within reach an object placed on the opposite end of the support (e.g., Piaget, 1952; Willatts, 1989).

Only one experiment has been completed to date. This experiment tested whether 6½-month-old infants realize that pulling the near end of a support is sufficient to bring within reach an object placed on the far end of the support, but not an object placed next to the support (Baillargeon, DeVos, & Black, 1992). The infants watched a possible and an impossible test event (see Fig. 9.16). At the start of each event, the infants saw a rigid support (a long, narrow platform covered with brightly colored paper) lying across the floor of the apparatus, and a small toy bear. After a few seconds, a screen was pushed in front of the objects, hiding them from view. The upper right corner of this screen was missing, creating a small window. Next, a hand reached behind the screen's right edge, took hold of the support's right end, and pulled it until the bear's head became visible in the screen window. The hand then reached behind the screen, grasped the bear, and brought it out from behind the screen. The only difference between the two test events was in the location of the bear at the start of the event. In the possible event, the bear was placed on the left end of the support; in the impossible event, the bear was placed on the floor of the apparatus, to the left of the support.

The infants looked reliably longer at the impossible than at the possible event, suggesting that they (a) represented the existence and the location of the bear

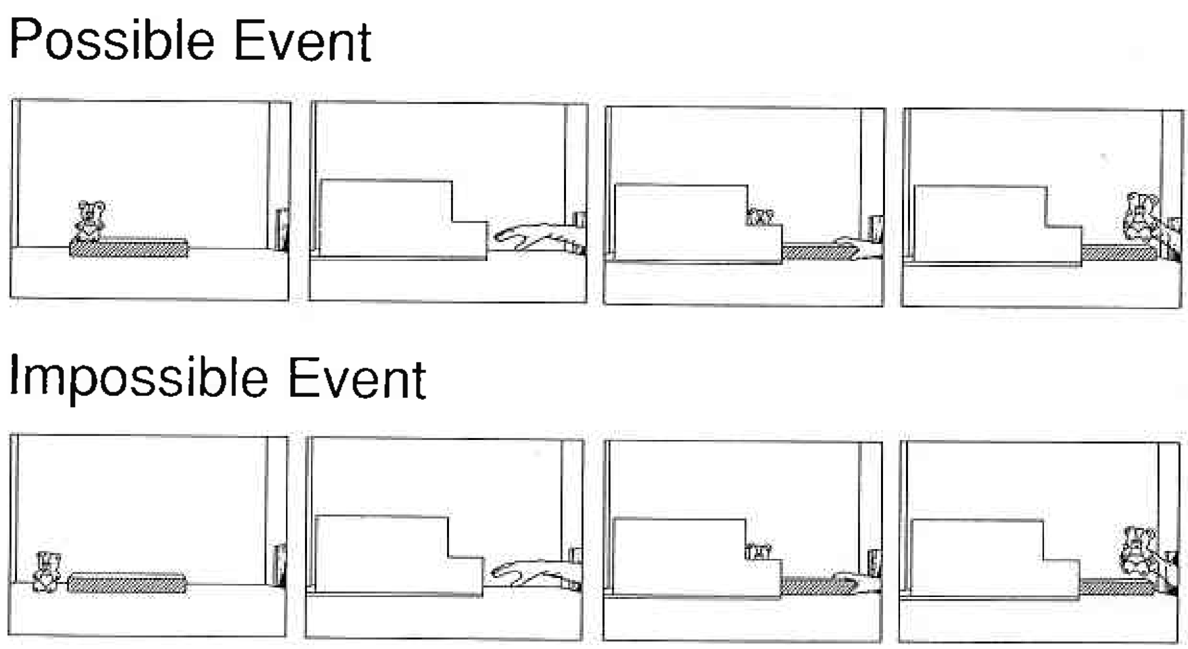

FIG. 9.16. Schematic drawing of the events shown to the infants in Baillargeon, DeVos, & Black (1992).

and the support behind the screen; (b) understood that pulling the support was sufficient to bring the bear to the window when the bear stood on, but not off, the support; and thus (c) were surprised in the impossible event to see the bear appear in the window. Support for this interpretation was provided by pretest trials that indicated that the infants had no reliable preference for seeing the bear off as opposed to on the support.

The findings of the experiments presented in this section indicate that infants aged 5½ to 6½ months have little difficulty (in some situations, at least) determining what actions can and what actions cannot result in the retrieval of an object placed out of reach beneath a cover or at the far end of a support. Evidence that young infants can readily identify valid means–end sequences argues against the hypothesis that infants fail to plan such sequences because their knowledge of the operators involved in the sequences is inaccurate or incomplete.

To what, then, should one attribute young infants' inability to plan means–end sequences? One possibility, already alluded to, is that young infants are unable to select or chain appropriate operators, even when these are well-known to them. At least two explanations could be advanced for this inability. One is that young infants lack a subgoaling ability—an ability to form sequences of operators such that each operator satisfies a subgoal that brings infants one step closer to their goal. This explanation seems unlikely given that young infants routinely perform what appear to be intentional series of actions directed at single objects. An example of such a goal-directed action sequence might be infants' reaching for and grasping a bottle, bringing it to their mouths, and sucking its nipple. Piaget (1952) described many sequences of this type. Several of his observations involve his children's responses to chains suspended from rattles attached to their bassinet hood. For example, Piaget noted the following: "At 0;3(14) Laurent looks at the rattle at the moment I hang up the chain. He remains immobile for a second. Then he tries to grasp the chain (without looking at it), brushes it with the back of his hand, grasps it but continues to look at the rattle without moving his arms. Then he shakes the chain gently while studying the effect. Afterward he shakes it more and more vigorously. A smile and expression of delight" (p. 163). It is very difficult to imagine how an infant might be capable of such clearly intentional actions and yet lack a subgoaling ability. Laurent's reaching for, grasping, and shaking the chain are all actions performed in the service of his goal, experienced from the start, of shaking the rattle.

A second explanation for young infants' inability to chain operators in means–end sequences is that young infants possess a subgoaling ability but have difficulty with situations in which the performance of the means would put them in apparent conflict with the achievement of their goal. That is, if infants want to grasp a toy placed under a cover, or at the far end of a cover, then grasping the cover puts them in apparent conflict with their goal of grasping the toy. Similarly, reaching around a screen to retrieve an object placed behind the screen may be difficult for infants because it puts them in the position of having to reach away from where they know the object to be.

Exactly why infants have difficulty with these conflict situations is unclear. However, it should be noted that adults often show similar difficulties. Klahr (personal communication, April 16, 1990) has found that naive adults who are given the Tower of Hanoi problem will avoid performing moves that are in apparent conflict with their goal, even though these counterintuitive moves are, in fact, the correct ones. According to this second explanation, then, infants would be in the same position as adults who, when faced with physical problems whose solutions require counterintuitive actions, find themselves able to *identify* but not to *generate* correct solutions to the problems.

Why do Infants Search in the Wrong Location for Hidden Objects?

Piaget (1954) attributed infants' perseverative errors in the AB search task to limitations of their object concept. Infants, Piaget maintained, do not conceive of the hidden object as a separate entity whose displacements are regulated by physical laws, but as a thing "at the disposal" of their action: They return to A after watching the experimenter hide the object at B because they believe that by repeating their action at A they will again produce the object.

The results reported in the previous sections argued against Piaget's interpretation of infants' AB errors. These results indicated that infants aged 4 months and older are able to represent and to reason about the location of one or more hidden objects. Further evidence against Piaget's interpretation came from reports that AB errors rarely occur when infants are allowed to search immediately after the object is hidden at B; errors occur only when infants are forced to wait before they search (e.g., Diamond, 1985; Wellman et al., 1987). Furthermore, the older the infants, the longer the delay necessary to produce errors (e.g., Diamond, 1985; Fox, Kagan, & Weiskopf, 1979; Gratch, Appel, Evans, LeCompte, & Wright, 1974; Harris, 1973; Miller, Cohen, & Hill, 1970; Wellman et al., 1987). Thus, according to Diamond's (1985) longitudinal study, the delay needed to elicit AB errors increases at a mean rate of 2 seconds per month, from less than 2 seconds at 7½ months to over 10 seconds by 12 months. There is no obvious way in which Piaget's theory can explain these findings.

In recent years, several interpretations have been proposed for infants' search errors (e.g., Bjork & Cummings, 1984; Diamond, 1985; Harris, 1987, 1989; Kagan, 1974; Schacter, Moscovitch, Tulving, McLachlan, & Freedman, 1986; Sophian & Wellman, 1983; Wellman et al., 1987). One hypothesis is that these errors reflect the limits of infants' recall memory, with increases in the delay infants tolerate without producing errors corresponding to increases in their retention capacity (e.g., Kagan, 1974). There is a long-standing assumption within the field of infant memory (e.g., Bruner, Olver, & Greenfield, 1966; Piaget, 1951, 1952) that recognition memory is present during the first weeks of life, whereas recall memory does not become operative until late in infancy. Investigations of recognition memory using habituation and preferential-looking paradigms have shown that by 5 months of age infants can recognize stimuli after delays of several hours, days, and even weeks (e.g., Fagan, 1970, 1973; Martin, 1975). These data contrast sharply with those obtained with the AB search task and, it would seem, give credence to the notion that recall memory emerges long after recognition memory and is at first exceedingly fragile, lasting at most a few seconds.

There are serious grounds, however, to doubt explanations of infants' search errors in terms of a late-emerging and easily disrupted recall capacity. Meltzoff (1988) recently reported experimental evidence that young infants can recall information after intervals considerably longer than those used in the AB search task. In Meltzoff's study, 9-month-old infants watched an experimenter perform three actions on novel objects; 24 hours later, they were given the same objects to manipulate. The results indicated that half of the infants spontaneously imitated two or more of the actions they had observed on the previous day. This finding (which was supported by findings from control conditions) suggested that by 9 months of age, if not before, infants can recall information after a 24-hour delay.

The hypothesis that infants' perseverative and random search errors reflect the general limits of their recall memory is thus unlikely (because infants perform successfully in different circumstances with longer delays), but perhaps this hypothesis could be revised to render it more plausible. One could propose that infants' search errors stem from the absence or the immaturity of a *specific* recall mechanism that is critical for success on the AB task but not on Meltzoff's (1988) delayed imitation task. Comparison of the two tasks suggests several candidate mechanisms. For instance, the AB task requires infants to update the information they have in memory as the object's location is changed; no such updating is needed in Meltzoff's task. A difficulty with this particular candidate, however, is that infants perform well on the AB task with short delays, indicating that they have no trouble updating information.

A more likely candidate for the specific recall mechanism implicated in infants' search errors is an inability to hold updated information in memory. We have just seen that infants have little difficulty updating information, and we know from Meltzoff's data that they can hold information for long delays. Infants' search errors, it might be hypothesized, stem from an inability to correctly perform both of these tasks at once.

In recent years, several versions of this hypothesis have been put forth (e.g., Diamond, 1985; Harris, 1973, 1989; Schacter & Moscovitch, 1983; Sophian & Wellman, 1983; Wellman et al., 1987). For example, one account of infants' AB errors assumes that infants can update information about the object's hiding place but can retain this information only for brief delays because of an extreme sensitivity to proactive interference (e.g., Harris, 1973; Schacter & Moscovitch, 1983). According to this view, as infants grow older, they become able to withstand longer and longer delays before the B representation becomes supplanted by the A representation formed on the previous trial. Another account maintains that both the A and B representations remain available in memory. However, infants rapidly forget or dismiss the fact that the B representation represents the object's *current* location. When deciding whether the object is hidden at A or at B, before engaging in search, infants tend to choose the prior A location because of an inadequate selectivity rule (e.g., Sophian & Wellman, 1983), of a mistaken attempt to infer the object's current location from its prior location (e.g., Wellman et al., 1987), or of an undue reliance on long-term spatial information (e.g., Harris, 1989). In each case it is assumed that infants are more likely to choose the correct B location when there is no delay between hiding and search, and that with increasing age, infants choose correctly over increasingly long delays.

Do infants' search errors stem from some deficient recall memory mechanism? A series of experiments were carried out to examine this hypothesis (Baillargeon & Graber, 1988; Baillargeon, DeVos, & Graber, 1989). We reasoned that if infants are unable to update, hold, and selectively attend to information about an object's current location, they should perform poorly in *any* task requiring them to keep track of trial-to-trial changes in an object's location. The task we devised was a nonsearch task (see Fig. 9.17). In this task, 8-month-old infants watched a possible and an impossible test event. At the start of each event, the infants saw an object standing on one of two identical placemats located on either side of the infants' midline. After a few seconds, identical screens were slid in front of the placemats, hiding the object from the infants' view. Next, a human hand, wearing a long silver glove and a bracelet of jingle bells, entered the apparatus through an opening in the right wall and "tiptoed" back and forth in the area between the right wall and the right screen. After frolicking in this fashion for 15 seconds, the hand reached behind the *right* screen and came out holding the object, shaking it gently until the end of the trial. The only difference between the two test events was in the location of the object at the start of the trial. In the possible event, the object stood on the right placemat; in the impossible event, the object stood on the left placemat, and thus should not have been able to be retrieved from behind the right screen. The infants saw the possible and the impossible events on alternate trials (order was, as always, counterbalanced) until they had completed three pairs of test trials.

The results indicated that the infants looked reliably longer at the impossible than at the possible event. Furthermore, the infants showed the same pattern of looking on all three pairs of test trials. In a second experiment, the hand reached behind the *left* screen for the object; the position of the object during the possible (left screen) and the impossible (right screen) events was thus reversed. The infants again looked reliably longer at the impossible than at the

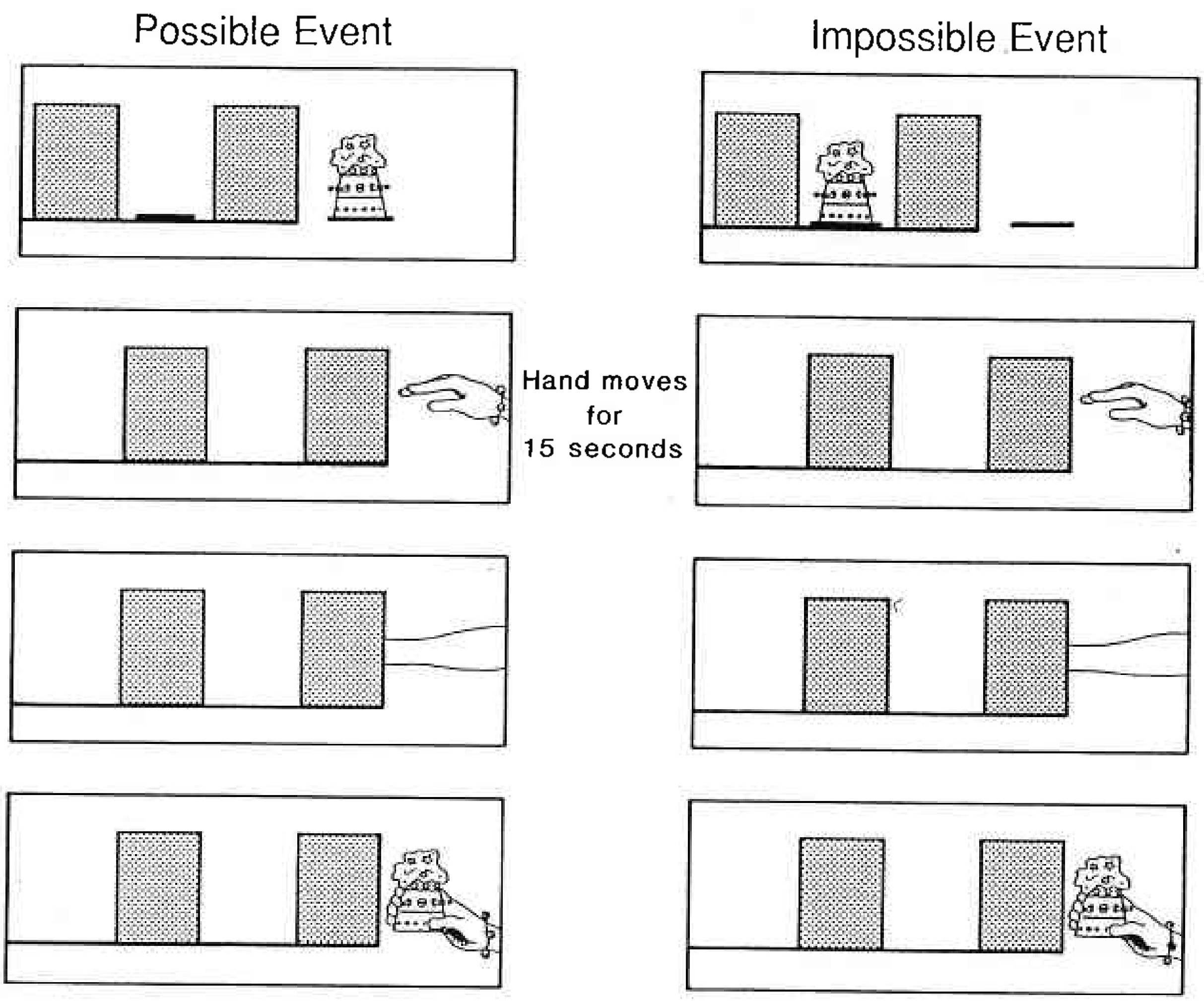

FIG. 9.17. Schematic drawing of the events shown to the infants in Baillargeon and Graber (1988).

possible event, and did so on all three test pairs. Together, the results of these two experiments suggested that the infants (a) registered the object's location at the start of each trial; (b) remembered this location during the 15 seconds the hand tiptoed back and forth; and (c) were surprised to see the object retrieved from behind one screen when they remembered it to be behind the opposite screen.

In our next experiments, we tested 8-month-old infants with delays of 30 and 70 seconds (Baillargeon, DeVos, & Graber, 1989). The infants again looked reliably longer at the impossible than at the possible event, indicating that they remembered the object's location during even the 70-second delay.

The results of these experiments revealed that 8-month-old infants have no difficulty remembering trial-to-trial changes in an object's hiding place after delays of 15, 30, and even 70 seconds. These results contrasted sharply with those obtained with the standard AB task: Investigators have found that 8-month-old infants typically search perseveratively after a 3-second delay (e.g., Butterworth, 1977; Diamond, 1985; Fox et al., 1979; Gratch & Landers, 1971; Wellman et al., 1987). The present results thus cast serious doubts on attempts to explain infants' search errors in terms of a deficient memory mechanism.

To what, then, should one attribute infants' search errors? One possibility (suggested by my husband, Jerry DeJong) is that these errors reflect problem solving difficulties caused by the demands of planning search actions. In order to describe this hypothesis, we must first distinguish between two types of problem solving, which may actually constitute opposite ends of a single continuum. One, *reactive* type corresponds to situations in which solutions are produced immediately, without conscious reasoning. Operators stored in memory and whose conditions of application are satisfied are simply "run off" or executed. An example of such problem solving might be reaching for an object whose location is known or driving home along a familiar route. The second, *planful* type of problem solving corresponds to situations in which solutions are generated through an active reasoning or computation process. An example of this second type of problem solving might be finding an object whose location can be deduced from available cues or planning a trip to a novel location. It is assumed that because the second type of problem solving is effortful, individuals use it only when no other avenues are available, preferring, whenever possible, to rely on previously computed solutions rather than generate new ones. Hence, when a problem situation is perceived to be similar to a previously experienced situation, individuals will attempt to apply the solution computed in the initial situation, thus engaging in reactive as opposed to planful problem solving (see Logan, 1988; Suchman, 1987, for interesting discussions of similar concepts).

To account for infants' performance in the AB search task, we must make two assumptions. The first is that, with *short* delays, infants engage in reactive problem solving: they "run off" an already existing operator to retrieve the object on both the A and the B trials. The second assumption is that, with *long* delays, for reasons that are still unclear, infants cannot use the short-delay operator. This leads them to perform differently on the A and the B trials. On the A trial, infants engage in planful problem solving: They compute a solution (i.e., determine where and how to find the object) and store this solution in memory. On the subsequent B trial, instead of recomputing a solution, infants engage in reactive problem solving and simply execute the solution they have just stored in memory, leading to perseverative errors. It is plausible that the overall similarity of the task context in the A and B trials lures infants into thinking "Aha, I know just what to do here!", and into blindly applying what is no longer an appropriate solution.

Two pieces of evidence are consistent with the hypothesis that infants' search errors reflect not memory limitations but deficiencies in problem solving. One such piece is that infants produce perseverative errors in the AB search task even when the object is visible at B instead of being hidden at B (e.g., Bremner

& Knowles, 1984; Butterworth, 1977; Nielson, 1982; see Wellman et al., 1987 for review and discussion). This finding creates serious difficulties for memory accounts but is easily explained by the notion that infants, instead of performing a close analysis of the task situation and computing the correct solution, are simply repeating a previously successful solution.

The other piece of evidence concerns data collected with tasks where no demands are made on infants' memory and yet perseverative errors very similar to those obtained in the AB task are found. Two such tasks are the locomotor detour tasks designed by Rieser, Doxsey, McCarrell, and Brooks (1982) and by Lockman and Pick (1984). Rieser et al. (1982) tested 9-month-old infants' ability to use auditory information to select an open as opposed to a blocked route to get to their mothers. Each infant and his or her mother sat on opposite sides of an opaque barrier; a side barrier stood perpendicular to the front barrier on the mother's left or right (the position of the side barrier on each trial was randomly determined). The front barrier was sufficiently high so as to hide both the mother and the side barrier from the infant. At the start of each trial, the mother asked the infant to join her behind the front barrier. The mother's calls were differentially reflected on her left and right sides because one side was open and the other side closed. The results indicated that on the initial trial the infants crawled or walked to the open side to find their mothers, suggesting that they detected the auditory cues that specified the location of the side barrier; on subsequent trials, however, the infants merely repeated the left or right direction of their first response. Lockman and Pick (1984) examined 12-month-old infants' ability to go around a barrier by the shortest route to get to their mothers. Each infant and his or her mother were positioned on opposite sides of one end of an opaque barrier (the left and right ends of the barrier were used on alternate trials). The infant could not step over the barrier but could see the mother above it. Lockman and Pick found that on the initial trial the infants chose the shortest route to go to their mothers; on subsequent trials, however, the infants tended to repeat their first response, going to their mothers via the same side across trials.

The results of these two detour tasks are very similar to those obtained in the AB search task with longer delays. On the initial trial, infants analyze the task situation and compute the correct solution (i.e., determine where to find the object hidden or visible at A, use auditory cues to decide which path to their mother is open and which path is blocked, and select the barrier end that constitutes the shortest route to their mother). On the subsequent B trial, however, instead of reanalyzing the situation and computing a novel solution, infants simply repeat the solution they performed successfully on the previous trial.

The account of infants' perseverative errors in terms of problem solving deficiencies possesses two additional advantages over alternative hypotheses. One is that it contradicts the view that these errors are peculiar responses characteristic of infancy but quite distinct from anything that occurs later in development. On the contrary, it leads us to view infants' perseverative errors on a continuum with or in the same light as errors produced by older subjects in other tasks. A number of tasks have been found in which adults perseverate by using in one context a solution devised or learned in another, superficially similar context. A well-known example of this phenomenon is the Luchins' water jar problem (A. S. Luchins, 1942; A. S. Luchins & E. H. Luchins, 1950; cited in Mayer, 1983). Another example is the "Moses illusion." Adult subjects who are asked, "How many animals of each type did Moses bring on the ark?" usually answer, "Two, a male and a female," without realizing that Moses was mentioned rather than Noah (e.g., Reder & Kusbit, 1991); Ross (1984) provided related evidence.

Children, too, can be lulled by context similarity into producing perseverative responses. An anecdote involving my son Antoine, aged 28 months, illustrates this point well. One morning I asked Antoine to play a guessing game with me; I would describe various objects and he would guess what they were. I said I was thinking of an animal with a very, very long neck, and Antoine correctly guessed a giraffe. I then said I was thinking of something he put on his feet to go outside to keep his toes warm, and Antoine correctly guessed boots. Later that day, I asked Antoine to play our guessing game a second time. I first said I was thinking of an animal with a very, very long neck, and Antoine again correctly guessed a giraffe. My next question was, "I am thinking of something you put on hour head when you go outside to keep your ears warm," and Antoine quickly responded "Boots." Because my son knew the difference between boots and hats and was familiar with both words, I concluded that he had been lulled by the similarity in context to repeat a previously correct but now inappropriate solution. Examples of this type are probably extremely common.

Two points about this anecdote are worth nothing. One is that my son was much quicker, during our second game session, at answering my questions; this is, of course, exactly what one would expect (shorter latencies) if answers are retrieved from memory rather than being computed on the spot. The second is that Antoine did not spontaneously realize he had erred in his answer to the second question. He did not behave as someone who knew full well the correct answer was *hat* but could not inhibit his prior response *boots*. He seemed perfectly satisfied with his answer, and did not change it until I repeated the question to him with appropriate exclamations and emphasis.

In brief, what I am claiming is that infants, like older children and adults, can be lured by overall context similarity into retrieving previously computed responses that changes in the context have rendered inappropriate. The main difference between infants and older subjects, in this account, is that infants are less likely to notice changes, or to integrate changes in the planning of future responses, and so are more prone to perseveration errors. Additional research is needed to specify the conditions under which infants are likely to notice contextual changes and to explain how this set of conditions is modified with age.

The second advantage that the problem-solving deficiency explanation has over alternative accounts of infants' AB errors is that it can be integrated relatively easily with the explanation, discussed in the previous section, of young infants' failure to search for hidden objects. Briefly, it is assumed that infants fail to search because they are unable to plan means–end sequences of actions; and that they search perseveratively, once they begin to search, because they are overly inclined (for reasons that are still unspecified) to rely on previously computed means–end sequences, rather than recompute or replan new ones. Furthermore, in both cases, infants show themselves better able to identify than to generate correct action sequences: as shown earlier, infants identify sequences that can result in the recovery of objects placed under obstacles or at the far end of supports long before they produce these sequences themselves (Baillargeon et al., 1990, 1992); in addition, infants identify context-appropriate searches after delays of 15, 30, and even 70 seconds long before they search correctly with similar delays (Baillargeon & Graber, 1988; Baillargeon et al., 1989).

CONCLUSION

The research summarized in this chapter has implications for at least three areas of infant development: object permanence, physical reasoning, and search. They are discussed in turn.

Object Permanence

When adults see an object occlude another object, they typically assume that the occluded object (a) continues to exist behind the occluding object; (b) retains its physical and spatial properties; and (c) remains subject to physical laws. Piaget (1954) proposed that infants initially do not share adults' beliefs about occlusion events, and adopt these beliefs one by one over the first two years of life.

The findings reported in this chapter clearly contradict Piaget's proposal. Consider the many experiments that obtained positive results with infants aged 3½ to 5½ months: the rotating screen experiments (Baillargeon, 1987a, 1991, 1992; Baillargeon et al., 1985), the rolling car experiments (Baillargeon & DeVos, 1991), the sliding rabbit experiments (Baillargeon & Graber, 1987; Baillargeon & DeVos, 1991), and the searching hand experiments (Baillargeon et al., 1990). The infants in these experiments seemed to have no difficulty representing the existence of one, two, and even three hidden objects. Furthermore, the infants represented many of the properties of the objects, such as their height, location, and trajectory. Finally, the infants expected the objects to behave not in capricious and arbitrary ways but in the same regular and predictable ways as visible objects. In particular, the infants realized that hidden objects, like visible objects, cannot move through the space occupied by other objects and cannot appear at two separate points in space without having traveled from one point to the other.

Thus, it appears that, far from adopting adults' beliefs about occlusion events in a stage-like manner over a protracted period of time, infants possess these beliefs from a very early age. Another way of stating this conclusion is to say that infants' understanding of occlusion events is qualitatively similar to that of older children and adults. This is not to say, of course, that no development remains to take place. Indeed, we saw several instances in which older infants' performance was distinctly better than that of younger infants. However, these differences seem to reflect improvements in infants' physical reasoning abilities, rather than changes in infants' conception of occluded objects.

Physical Reasoning

The research reported in this chapter suggests three hypotheses about the development of infants' physical-reasoning. One is that in their first pass at understanding physical events, infants construct general, all-or-none representations that capture the essence of the events but few of the details (e.g., a rotating screen will stop when an obstacle is placed in its path; the presence of a protuberance in a soft cloth cover signals the presence of an object beneath the cover). These initial, core representations are progressively elaborated as infants identify variables that are relevant to the events' outcomes (e.g., the location, height, and compressibility of the obstacles in the path of a rotating screen can be used to determine at what point the screen will stop; the size of the protuberance in a cloth cover can be used to judge the size of the object beneath the cover). Infants incorporate this accrued knowledge into their reasoning, resulting in increasingly accurate predictions over time.

The second hypothesis is that, in reasoning about variables, infants can reason first qualitatively and only after some time quantitatively about the effects of these variables. Recall that the 4½-month-old infants in the rotating screen experiments (Baillargeon, 1991) and the 12½-month-old infants in the soft-cover experiments (Baillargeon & DeVos, 1992) were able to solve the two-box or the two-cover tasks before they were able to detect violations in the one-box or the one-cover task. It does not seem unreasonable that development should proceed in this manner. Indeed, infants' success in generating qualitative solutions to physical problems may facilitate their production of quantitative solutions to the same problems. For example, having determined, by using the visible box, at what point the screen will encounter the occluded box, infants might be in a better position, when the visible box is removed, to compute a quantitative estimate of when the screen should stop.

The foregoing discussion presupposes that infants' approach to learning about physical events—the representation of core events and the progressive identification of pertinent variables—reflects the operation of innate, highly constrained learning mechanisms that direct infants' attention to particular observations and guide the quantitative and qualitative analyses of these observations. The third hypothesis suggested by the present research is that, although infants' approach to learning about the physical world remains the same throughout infancy, which events are understood at which ages depends on a host of developmental factors. These include infants' visual abilities (what cannot be seen cannot be understood) and motoric capacities (some knowledge may arise from manipulations that cannot occur until infants can reach successfully, sit with support, and so on). In addition, there are undoubtedly cognitive factors having to do with the development of infants' memory and representational abilities. With respect to the latter factor, the present research suggests that infants can reason about objects they have seen, even after these objects are hidden from view, long before they can make inferences about hidden objects. The fact that young infants appear limited to physical reasoning based on concrete representations clearly must restrict the range of physical problems they can solve.

The three hypotheses described in this section suggest new directions for research on the development of infants' physical reasoning. How do infants go about forming representations of core events? How do they identify variables that are relevant to these events? How do they devise qualitative and quantitative strategies for reasoning about the effects of these variables? Do infants integrate their representations of events? If yes, how should these networks of representations be described? Finally, what are the sensorimotor and cognitive factors that interact with infants' approach to learning about the physical world to yield the knowledge revealed in the present experiments?

Search

Researchers have identified two distinct stages in the early development of infants' search behavior: Prior to about 7½ months of age, infants do not search for objects they have observed being hidden, and prior to about 12 months of age, infants do search for hidden objects but their performance is fragile and easily disrupted by task factors, such as the introduction of a delay between hiding and retrieval. According to the arguments put forth in this chapter, both of these stages reflect limitations in problem solving. During the first stage, infants are unable to plan means–end sequences, such as search sequences, possibly because the performance of the means (e.g., grasping a cover) places them in an apparent conflict with the achievement of their goal (grasping the toy beneath the cover). During the second stage, infants become able to plan search sequences but are overly inclined, under certain conditions, to repeat previously planned sequences rather than to compute new and context-sensitive sequences. Interestingly, at each stage infants show themselves able to *evaluate* correct sequences even when they cannot *generate* them. Specifically, infants can identify correct sequences for the retrieval of a hidden object long before they spontaneously produce these sequences. Similarly, infants can identify context-appropriate searches after delays of 15, 30, and even 70 seconds long before they produce correct searches at comparable delays.

A salient aspect of the explanations proposed here is that they appeal to problem solving limitations that have already been identified in children and adults. Adults often have difficulty solving physical problems whose solutions depend on moves that are counterintuitive in that they appear to take one farther away from one's goal. Furthermore, adults can be lulled by overall context similarity in applying a previous solution that is no longer appropriate. Finally, in all these instances, adults typically have little difficulty recognizing accurate solutions, even when they have failed to generate them.

The general picture suggested by the present research is, thus, one in which the physical world of infants appears very similar to that of adults: Not only do infants and adults share many of the same beliefs and show many of the same physical reasoning abilities, but these abilities seem limited in the same ways.

Final Remarks

The research presented in this chapter is interesting for three reasons. One is that it yields a picture of infants as budding intuitive physicists, capable of detecting, interpreting, and predicting physical outcomes, which is radically different from the traditional portrayal of young infants as enclosed within a world in which an object is "a mere image which reenters the void as soon as it vanishes, and emerges from it for no objective reason" (Piaget, 1954, p. 11). Another reason is that it suggests several new directions for research on infants' acquisition and representation of physical knowledge and on the manifestation of this knowledge in tasks calling for manual and non-manual responses. The third reason is that, as we discover how infants attain, represent, and use physical knowledge, we come one step closer to understanding the central issue of the origins of human cognition.

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