CHAPTER ONE

How Do Infants Reason About Physical Events?

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Introduction

As adults, we possess a great deal of knowledge about the physical world: for example, we realize that an object continues to exist when hidden, that a wide object can fit inside a wide but not a narrow container, and that an object typically falls when released in midair. Piaget (1952, 1954) was the first researcher to systematically investigate the development of infants' physical knowledge. He examined infants' responses in various *action tasks* and concluded that young infants understand very little about physical events. For example, after observing that infants younger than 8 months do not search for objects they have watched being hidden, Piaget proposed that young infants lack a concept of *object permanence* and do not yet understand that objects continue to exist when hidden.

For the next several decades, Piaget's (1952, 1954) conclusion that young infants possess little or no knowledge about the physical world was generally accepted. (For reviews of this early research, see Bremner, 1985; Gratch, 1976; Harris, 1987). This state of affairs began to change in the 1980s, however, when researchers became concerned that exclusive reliance on action tasks as an investigative tool might underestimate young infants' physical knowledge. In order to search for an object hidden under a cloth, for example, infants must not only represent the existence and location of the object, but they must also plan and execute the appropriate means–end actions to retrieve it. Thus, young infants might represent the object but still fail to search for it because (a) they are unable to plan or execute the actions necessary to retrieve it (e.g., Baillargeon, Graber, DeVos, & Black, 1990; Diamond, 1991; Willatts, 1997), or (b) they can plan and execute these actions but lack sufficient information-processing resources to simultaneously represent the hidden object and carry out the actions required to retrieve it (e.g., Hespos &

The preparation of this chapter was supported by a grant from the National Institute of Child Health and Human Development to Renée Baillargeon (HD-21104). We would like to thank Jerry DeJong and Cindy Fisher for many helpful discussions.

The Wiley-Blackwell Handbook of Childhood Cognitive Development, Second edition.
Edited by Usha Goswami.

Published 2014 by John Wiley & Sons, Ltd.

Baillargeon, 2008; Keen & Berthier, 2004; Lockman, 1984; see also Munakata, McClelland, Johnson, & Siegler, 1997; Shinskey, 2002; Shinskey & Munakata, 2001).

These methodological concerns led investigators to seek alternative approaches for exploring young infants' physical knowledge. Their research efforts can be roughly organized into three successive, overlapping waves. The first wave established that, contrary to Piaget's (1952, 1954) claims, even young infants possess some expectations about physical events. The second wave began to systematically examine the development of infants' physical knowledge and brought to light striking patterns of successes and failures in infants' responses to physical events. Finally, the third, ongoing, wave builds on these preceding efforts and attempts to specify both how infants reason about physical events and what cognitive architecture makes this reasoning possible. In what follows, we first briefly review findings from the first and second waves. In the remainder of the chapter, we focus on the third wave and present a three-system account of how infants reason about physical events.

First Wave: The Competent Infant

One of the major alternative approaches used to explore young infants' physical knowledge relies on the long-established finding that infants (like older children and adults) tend to look longer at stimuli they perceive to be novel as opposed to familiar (e.g., Fantz, 1956). Looking-time tasks have two main advantages over action tasks: they can be administered to very young infants, and they can be modified endlessly to explore subtle facets of infants' responses to a wide array of physical events. The most commonly used looking-time task is the *violation of expectation* (VOE) task. In a typical experiment, infants see two test events: an expected event, which is consistent with the expectation being examined in the experiment, and an unexpected event, which violates this expectation. With appropriate controls, evidence that infants look reliably longer at the unexpected than at the expected event is taken to indicate that infants (a) possess the expectation under investigation; (b) detect the violation in the unexpected event; and (c) are "surprised" by this violation. The term surprise is used simply as a shorthand descriptor, to denote a state of heightened attention or interest caused by an expectation violation (for discussion, see Wang, Baillargeon, & Brueckner, 2004).

The first wave of looking-time experiments on infants' physical knowledge indicated that even young infants possess expectations about a number of physical events (e.g., Baillargeon, Spelke & Wasserman, 1985; Leslie, 1984; Leslie & Keeble, 1987; Needham & Baillargeon, 1993; Spelke, Breinlinger, Macomber, & Jacobson, 1992; Woodward, Phillips, & Spelke, 1993). For example, VOE experiments examining object permanence in infants aged 2.5–6 months (see figure 1.1) revealed that infants were surprised when an object was placed behind a screen which then rotated through the space occupied by the object (e.g., Baillargeon, 1987, 1991); when an object moved through an obstacle behind a screen (e.g., Baillargeon, 1986; Spelke et al., 1992); when an object disappeared from behind a screen or from under a cover (e.g., Leslie, 1995; Wynn, 1992); and when an object was hidden in one location and then retrieved from a different location (e.g.,

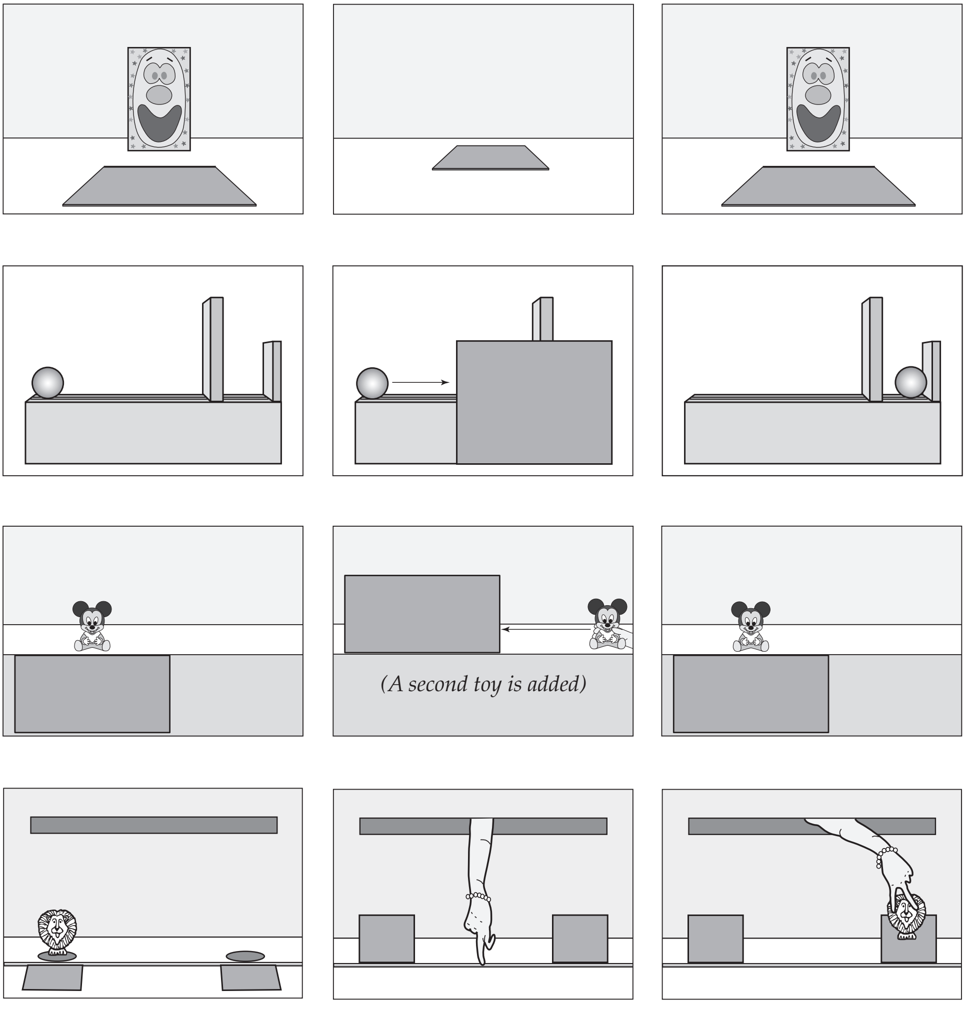

Figure 1.1 Examples of violations in experiments showing that young infants can represent hidden objects, as reported by Baillargeon (1987), Spelke et al. (1992), Wynn (1992), and Wilcox et al. (1996)

Newcombe, Huttenlocher, & Learmonth, 1999; Wilcox, Nadel, & Rosser, 1996). These and many other similar results provided consistent evidence that young infants realize that objects continue to exist when hidden. (For reviews, see Baillargeon, 1993; Spelke & Hespos, 2001).

The first wave of looking-time experiments on infants' physical knowledge helped bring about a revolution in researchers' characterization of young infants' cognitive abilities. For the greater part of the twentieth century, theoretical views had portrayed young infants as limited sensorimotor processors incapable of representation or thought (e.g., Bruner, 1968; Piaget, 1952, 1954). In marked contrast, these new experiments suggested that young infants were far more cognitively competent than had previously been suspected (evidence for this conclusion also came from experiments on infants' reasoning about psychological as opposed to physical events; e.g., Csibra, Gergely, Bíró, Koós, & Brockbank, 1999; Gergely, Nádasdy, Csibra, & Bíró, 1995; Premack & Premack, 1997; Woodward, 1998).

As might be expected, these groundbreaking claims of early cognitive competence were scrutinized in turn, and a heated controversy soon arose over the interpretation of looking-time findings (e.g., Baillargeon, 1999; Haith, 1998; Smith, 1999; Spelke, 1998). In particular, researchers offered deflationary accounts of young infants' apparent success in VOE object-permanence tasks. According to many of these accounts, infants looked longer at the unexpected than at the expected test event in each task because (a) familiarization or habituation events were used to introduce the task and (b) these events inadvertently induced a transient and superficial preference for the unexpected test event (e.g., Bogartz, Shinskey, & Schilling 2000; Bogartz, Shinskey, & Speaker, 1997; Cashon & Cohen, 2000; Thelen & Smith, 1994; for reviews, see Baillargeon, 2004; Wang et al., 2004).

Did infants' responses in VOE object-permanence tasks reflect a genuine ability to represent hidden objects, or meaningless preferences induced by the familiarization or habituation events shown in the tasks? Two lines of evidence supported the first of these interpretations. One line came from simple action tasks. Instead of using VOE tasks to explore young infants' responses to hidden objects, a number of researchers devised simple action tasks they had reason to believe would be less taxing than Piaget's (1952, 1954) manual search tasks. For example, some experiments asked whether young infants would search for an object that was "hidden" simply by extinguishing the room lights. The object could thus be recovered by a direct reach in the dark (e.g., Goubet & Clifton, 1998; Hood & Willatts, 1986). Other experiments asked whether young infants would succeed at searching for an object visually, as opposed to manually (e.g., Hofstader & Reznick, 1996; Ruffman, Slade, & Redman, 2005). Yet other experiments asked whether young infants would visually anticipate the reappearance of an object that was passing behind a screen (e.g., Kochukhova & Gredebäck, 2007; von Hofsten, Kochukhova, & Rosander, 2007). All of these simple action tasks yielded positive results with infants aged 4–6 months, providing converging evidence that young infants are able to represent hidden objects.

The other line of evidence came from experiments designed to test transient-preference accounts directly. According to these accounts, young infants should fail at VOE object-permanence tasks when given *no* familiarization or habituation trials: without such trials, infants could have no opportunity to form transient preferences, and they should therefore tend to look equally at the unexpected and expected test events. To test this prediction, young infants were given a VOE object-permanence task with test trials only (Wang et al., 2004). One experiment, for example, asked whether 4-month-olds realize that a wide object can be fully hidden inside a wide but not a narrow container (see figure 1.2). The infants saw a wide and a narrow test event. At the start of each event, an experimenter's gloved hand held a wide object above a wide (wide event) or a narrow (narrow event) container; the wide container was slightly wider than the object, and the narrow container was less than half as wide as the object. After a pause, a screen was raised to hide the container, and the hand then lowered the object into the container. Finally, the screen was lowered to reveal only the container; the object was not visible

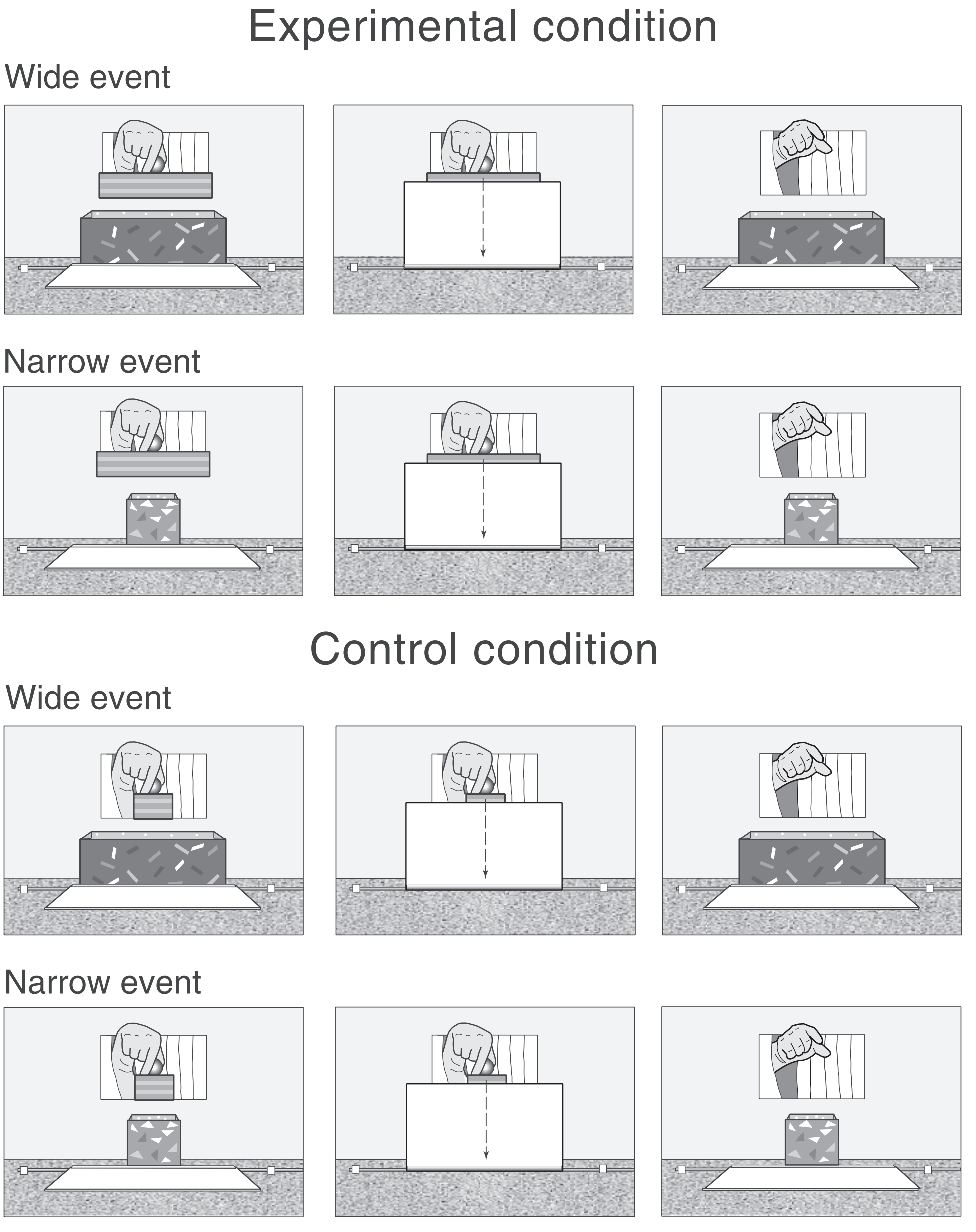

Figure 1.2 Test events used in the experimental and control conditions of Wang et al. (2004)

and was presumably hidden inside the container. This outcome was possible in the wide but not the narrow event: since the object was wider than the narrow container, it should have been impossible for the object to fit inside the narrow container. Infants in a control condition saw similar test events except that the object was much narrower and could be fully hidden inside either container. The infants in the experimental condition looked reliably longer at the narrow than at the wide event, whereas those in the control condition looked about equally at the two events. These results suggested that the infants (a) believed that the wide or narrow object continued to exist after it became hidden and (b) realized that the wide object could be fully hidden inside the wide but not the narrow container, whereas the narrow object could be fully hidden inside either container.

Together, these two lines of evidence were important for several reasons: they provided converging evidence that young infants can represent hidden objects; they supported the notion that infants who reveal a physical expectation in a VOE task will reveal the same expectation in an action task as long as the demands of the task do not overwhelm their limited information-processing resources; and they helped put to rest some of the concerns associated with VOE tasks.

Second Wave: Developmental Patterns

The first wave of looking-time experiments on infants' physical knowledge established that, contrary to traditional claims, even young infants possess expectations about physical events. However, little was known about how infants' physical knowledge *developed* during the first year of life. Initial investigations tended to focus on questions such as whether young infants are surprised if objects magically disappear, break apart, or pass through obstacles. Because the answers to these questions tended to be positive, no salient developmental patterns emerged.

The situation changed rapidly as researchers began asking more detailed questions about the effects of specific object properties in specific event categories. For example, although 4-month-olds were surprised when a wide object became fully hidden inside a narrow container, as we saw in the last section, they were *not* surprised when a tall object became fully hidden inside a short container (Hespos & Baillargeon, 2001a). By about 7.5 months of age, infants succeeded in detecting this violation – but they were *not* surprised if the tall object became fully hidden inside a short tube, instead of inside a short container (Wang, Baillargeon, & Paterson, 2005). In the course of these investigations, striking patterns of successes and failures thus began to emerge both *within* and *across* event categories, as we explain more fully below. (For reviews, see Baillargeon & Wang, 2002; Spelke & Hespos, 2002).

Developments Within Event Categories

As researchers began to study infants' expectations about specific event categories, it soon became apparent that whether infants succeeded or failed at detecting a violation in an event category depended on the particular expectation investigated. To illustrate, consider experiments on infants' expectations about occlusion events (i.e. events in which an object moves or is placed behind another object, or occluder). One series of experiments examined infants' ability to judge whether an object should be fully hidden when behind an occluder (see figure 1.3). At about 3 months of age, infants were surprised if an object

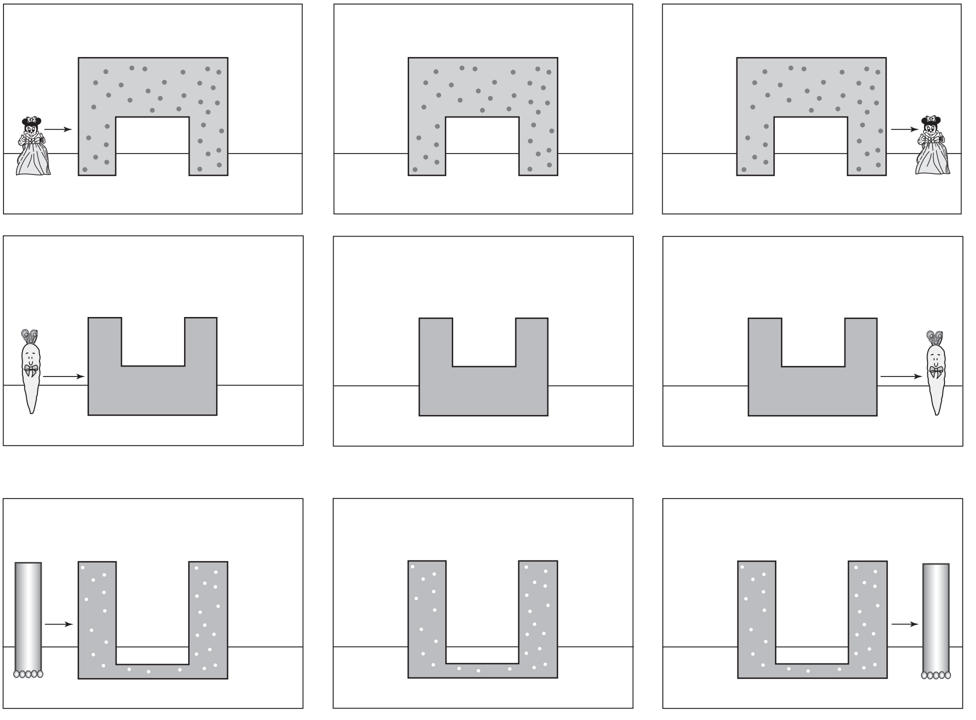

Figure 1.3 Examples of violations in experiments on young infants' ability to judge whether an object should remain hidden when passing behind an occluder, as reported by Aguiar and Baillargeon (2002), Baillargeon and DeVos (1991), and Luo and Baillargeon (2005)

remained hidden when passing behind a screen with a large opening extending from its lower edge (Aguiar & Baillargeon, 2002; Luo & Baillargeon, 2005). However, infants were not surprised if an object remained hidden when passing behind a screen with a large opening extending from its upper edge (Baillargeon & DeVos, 1991), and this held true even when the object was as tall as the screen, so that a large portion of the object should have become visible in the screen's opening (Luo & Baillargeon, 2005). By about 3.5 months of age, infants detected this violation, suggesting that they now attended to height information in occlusion events and expected tall objects to remain visible above short occluders (Baillargeon & DeVos, 1991; Hespos & Baillargeon, 2001a).

Another series of experiments on occlusion events examined infants' ability to notice impossible changes, or change violations, that took place while an object was briefly occluded (see figure 1.4). At about 4.5 months of age, infants were surprised if an object surreptitiously changed size or shape when passing behind a narrow screen (too narrow to hide two objects at once; Wilcox, 1999; Wilcox & Baillargeon, 1998). However, infants failed to detect other change violations: prior to about 7.5 months, infants were not surprised if an object changed pattern when passing behind a narrow screen (Wilcox, 1999; Wilcox & Chapa, 2004); furthermore, prior to about 11.5 months, infants were not surprised if an object changed color when passing behind a narrow screen (Wilcox, 1999; Wilcox & Chapa, 2004).[1]

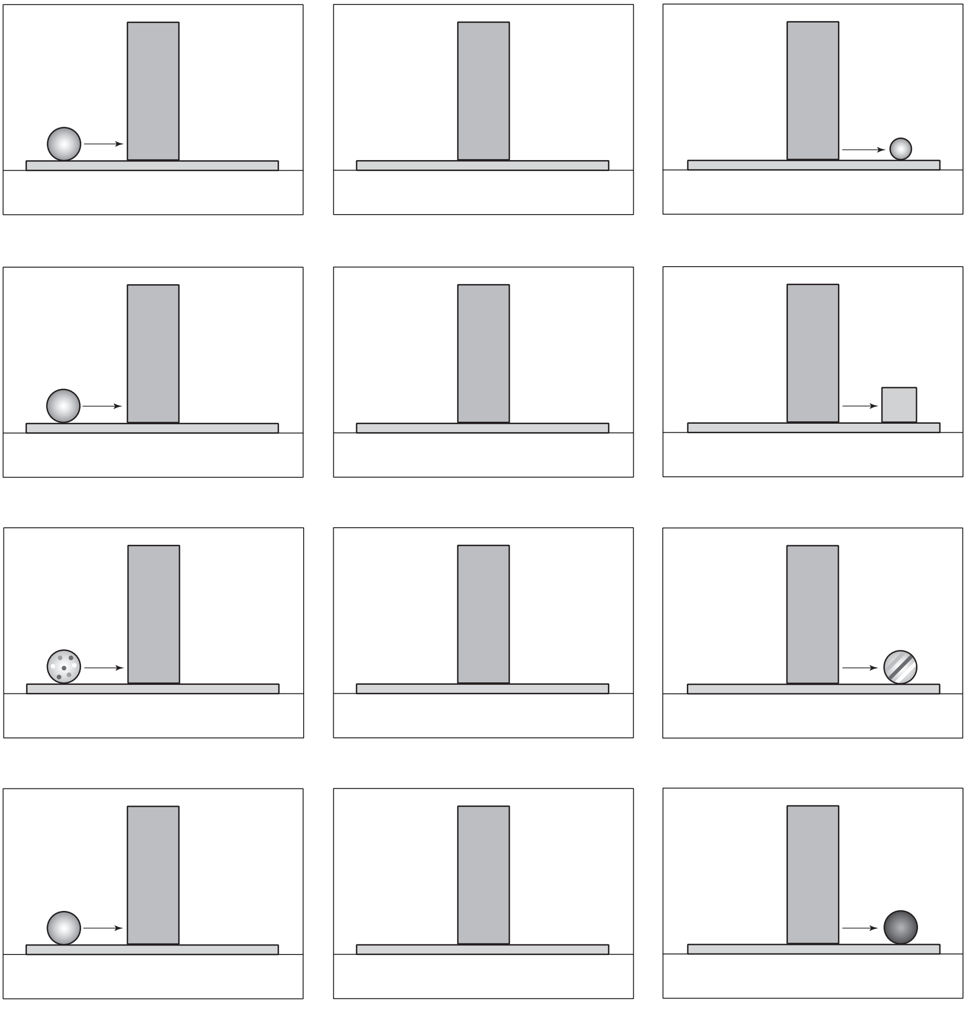

Figure 1.4 Examples of violations in experiments on young infants' ability to detect a surreptitious change to an object that is briefly occluded, as reported by Wilcox (1999)

Developments Across Event Categories

As researchers began to compare infants' physical expectations across event categories, further developmental patterns emerged. In some cases, infants seemed to acquire a physical expectation at about the same age in different event categories. To return to a previous example, 4-month-olds attended to width information in occlusion as well as in containment events: they were surprised if a wide object became fully hidden either behind a narrow occluder or inside a narrow container (Wang et al., 2004; see figure 1.2). In other cases, however, infants detected a violation in one event category, but failed to detect a similar violation in another event category. Thus, although 4.5-month-olds were surprised if an object changed shape when passing behind a narrow screen, as we just saw (Wilcox, 1999; Wilcox & Baillargeon, 1998), 5-month-olds were *not* surprised if an object changed shape when briefly buried in sand (Newcombe et al., 1999). These results suggested that there might be lags or *décalages* (to use a Piagetian term) in infants' acquisition of similar expectations in different event categories.

Of course, one difficulty with this conclusion was that the events being compared often differed in so many dimensions that it made it difficult to determine exactly why infants succeeded with one event category but failed with another. Subsequent investigations attempted to circumvent this difficulty by comparing infants' responses to *perceptually similar* events from different categories. In particular, a whole host of VOE experiments compared infants' responses to occlusion and containment events. In each experiment, the occluders used in the occlusion events were identical to the front walls of the containers used in the containment events, so that infants saw highly similar events in the two categories. These experiments revealed striking décalages in infants' acquisition of similar expectations in the two categories (see figure 1.5). Thus, although 4.5-month-olds were surprised if a tall object became almost fully hidden behind a short occluder, only infants aged 7.5 months and older were surprised if the object became almost fully hidden inside a short container (Hespos & Baillargeon, 2001a). Similarly, 7.5-month-olds detected a violation if an object became fully hidden behind a transparent occluder, but only infants aged 9.5 months and older detected a violation if the object became fully hidden inside a transparent container (Luo & Baillargeon, 2009). Finally, 12.5-month-olds were surprised if an object changed color when briefly hidden behind a small occluder (too small to hide more than one object), but they were not surprised if the object changed color when briefly hidden inside a small container (we still don't know at what age infants reliably detect this violation; Gertner, Baillargeon, Fisher, & Simons, 2009; Ng & Baillargeon, 2009).

Décalages were also observed in action tasks (e.g., Hespos & Baillargeon, 2006; Wang & Kohne, 2007). In one experiment, for example, 6- and 7.5-month-olds first played with a tall stuffed frog (see figure 1.6; Hespos & Baillargeon, 2006). Next, the frog was placed behind a large screen, which was then removed to reveal a tall and a short occluder (occlusion condition) or a tall and a short container (containment condition). The occluders were identical to the front halves of the containers; two frog feet protruded on either side of each occluder or through small holes at the bottom of each container. At both ages, infants were reliably more likely to search for the frog behind the tall as opposed to the short occluder; however, only the 7.5-month-olds were reliably more likely to search for the frog inside the tall as opposed to the short container (control infants who did not see the frog tended to reach about equally for the two occluders or containers).

The action results just described provided converging evidence for the décalage in infants' reasoning about height information in occlusion and containment events. Further experiments revealed that infants did not begin to attend to height information until about 12 months in covering events (e.g., events in which a cover, or inverted container, is placed over an object) and until about 14.5 months in tube events (e.g., events in which an object is placed inside a tube; e.g., Wang et al., 2005). In the case of tube events, for example, researchers found that, prior to about 14.5 months, infants were not surprised

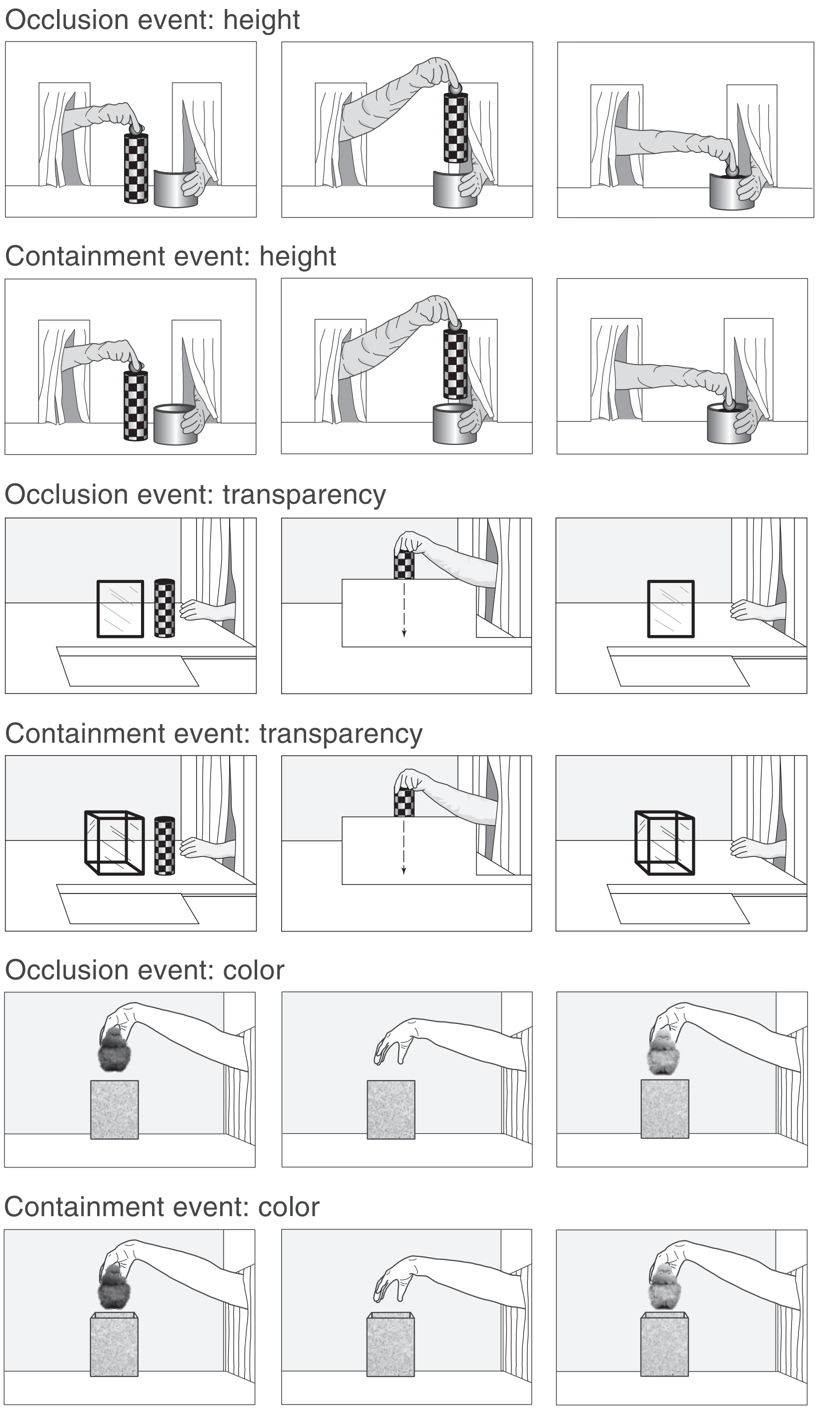

Figure 1.5 Décalages between occlusion and containment events in infants' reasoning about height information (Hespos & Baillargeon, 2001a), transparency information (Luo & Baillargeon, 2009), and color information (Ng & Baillargeon, 2009)

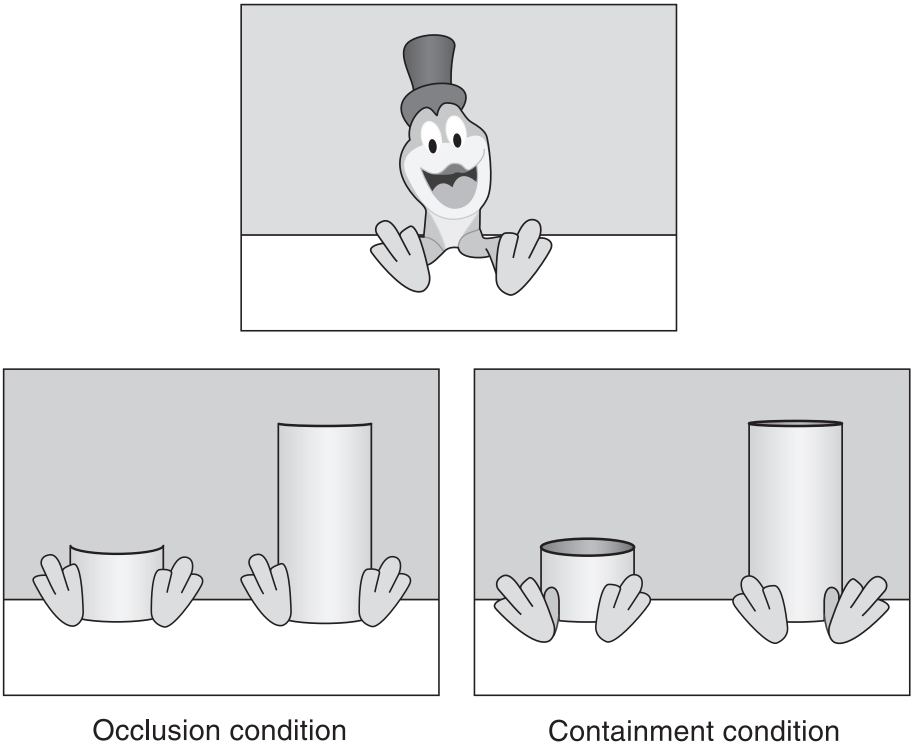

Figure 1.6 Test event used in Hespos and Baillargeon (2006)

if a tall object became fully hidden inside a short tube (Gertner et al., 2009; Wang et al., 2005), they were not surprised if an object changed height when briefly lowered inside a tall tube (Wang & Baillargeon, 2006), and they tended to search for a tall object inside either a tall or a short tube (Wang & Kohne, 2007).

Décalages With Perceptually Identical Events

In the last section, we saw that décalages can be observed in infants' responses to perceptually similar events from different categories. Remarkably, décalages have also been observed with *perceptually identical* events from different categories. These experiments took advantage of the findings (described above) that infants begin to attend to height information at about 7.5 months in containment events, but only at about 14.5 months in tube events.

In one experiment (Wang et al., 2005), 9-month-olds were presented in a brief orientation procedure with a tall and a short container (container condition) or a tall and a short tube (tube condition); the tubes were indistinguishable from the containers when standing upright. Next, the infants saw a tall and a short test event (see figure 1.7). At the start of each event, a tall object stood next to the tall (tall event) or the short (short

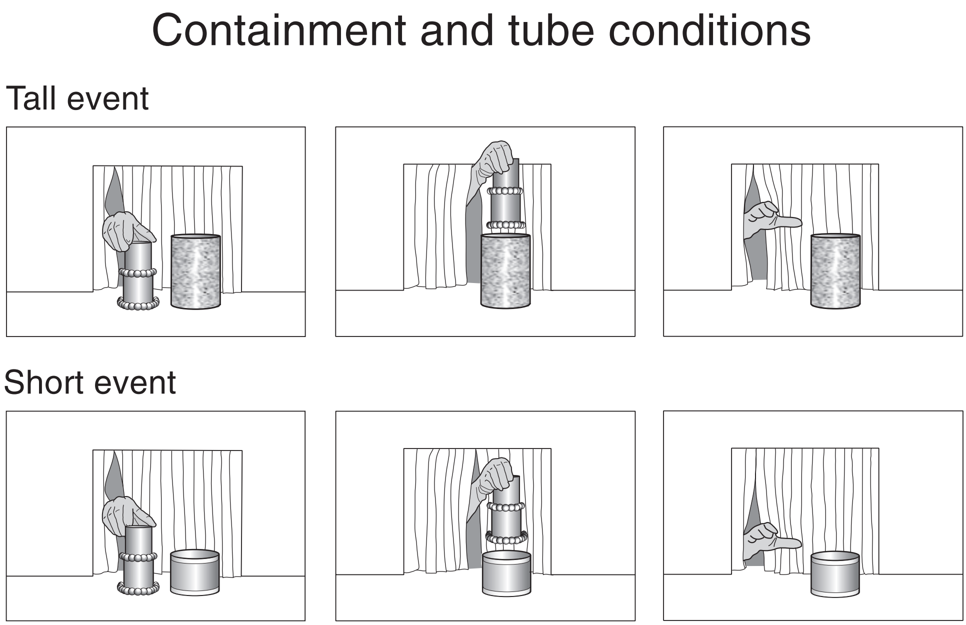

Figure 1.7 Test events used in Wang et al. (2005)

event) container/tube on the apparatus floor; the tall container/tube was slightly taller than the object, and the short container/tube was about half as tall as the object. In each event, an experimenter's gloved hand lifted the object and lowered it inside the container/tube until it became fully hidden. The infants in the container and tube conditions thus saw identical test events: only the information provided in the orientation procedure indicated to the infants in the tube condition that they were facing tubes rather than containers. The infants in the container condition looked reliably longer at the short than at the tall event, whereas those in the tube condition looked about equally at the two events. The infants thus detected the violation in the short event if they believed they were facing a container, but not if they believed they were facing a tube.

Décalages with perceptually identical containment and tube events have recently been observed in two other tasks (Li & Baillargeon, 2009). In a VOE task, 8-month-olds detected a violation if a tall object was much shorter after being briefly lowered inside a tall container, but they failed to detect a violation if the object was much shorter after being briefly lowered inside a tall tube. In an action task, 10-month-olds searched for a tall object inside a tall as opposed to a short container, but they searched for the same object inside either a tall or a short tube. In both tasks, the tubes were indistinguishable from the containers when upright, so that the infants saw perceptually identical test events.

The décalages discussed in this and in the previous section are not due to the fact that infants generally have more difficulty reasoning about containers as opposed to occluders, about covers as opposed to containers, or about tubes as opposed to covers and containers. In fact, even young infants can detect simple violations involving containers, covers, and tubes (e.g., Baillargeon, 1995; Hespos & Baillargeon, 2001b; Wang et al., 2005). What factors then, cause these décalages? Why do weeks or months sometimes separate infants' acquisition of similar expectations in different event categories? We return to this question in the next section.

Third Wave: An Account of Infants' Physical Reasoning

The first two waves of experiments on infants' physical knowledge painted a rather complex picture. Within each event category, some violations were detected at an early age, whereas others were not detected until much later. Across event categories, infants sometimes detected a violation when presented in the context of events from one category, but failed to detect the same violation when presented in the context of (perceptually similar or even identical) events from another category. Making sense of these intricate results required developing an account of infants' physical reasoning that made explicit (a) what information infants represent about physical events and (b) how infants interpret this information. Over the past few years, we have been working on developing such an account (e.g., Baillargeon, Li, Luo, & Wang, 2006; Baillargeon, Li, Ng, & Yuan, 2009).

Before we describe our account, two general comments may be helpful. First, our account focuses on very simple situations where infants reason about one or two successive events involving a small number of objects. This seems a reasonable starting point, because infants' performance often deteriorates when they are presented with two or more simultaneous events or with single events involving a large number of objects (e.g., Cheries, Wynn, & Scholl, 2006; Káldy & Leslie, 2005; Mareschal & Johnson, 2003; Sloane, Baillargeon, Simons, & Scholl, 2009). Second, the events we investigate are by and large simple everyday events that would have been familiar to our distant evolutionary ancestors (e.g., occlusion, containment, support, and collision events). At the present time, our account has little to say about events that involve complex cultural artifacts whose causal mechanisms are opaque to most adults – artifacts such as cell phones, computers, televisions, planes, or magic wands. Although infants may in some respects be prepared to learn how agents operate these complex artifacts (e.g., Csibra & Gergely, 2009; Muentener & Carey, 2009; Tomasello, Carpenter, Call, Behne, & Moll, 2005), these preparations are very different from those that concern us here.

Physical-Reasoning System and Causal Framework

Like several other researchers, we assume that infants are born equipped with a *physical-reasoning (PR) system* – an abstract, computational system that provides a skeletal causal framework for making sense of the displacements and interactions of objects and other physical entities (e.g., Carey & Spelke, 1994; Gelman, 1990; Leslie, 1995; Spelke et al., 1992). The PR system operates without conscious awareness: infants are not aware of the causal framework they use when reasoning about physical events, any more than young children are aware of the grammar of their language as they begin to understand and produce sentences.

When infants watch a physical event, the PR system builds a specialized *physical representation* of the event. Any information included in this representation becomes subject to the system's causal framework. This framework includes a number of explanatory concepts (e.g., internal energy, force; Baillargeon, Wu, Yuan, Li, & Luo, 2009; Leslie, 1995) as well as core principles. Of most relevance to the research described in this chapter is the *principle of persistence*, which states that, all other things being equal, objects persist, as they are, in time and space (e.g., Baillargeon, 2008; Baillargeon et al., 2009). The persistence principle has many corollaries, including but not limited to those of continuity, solidity, cohesion, and boundedness (e.g., Spelke et al., 1992; Spelke, Phillips, & Woodward, 1995). It specifies that an object cannot spontaneously appear or disappear (continuity), occupy the same space as another object (solidity), break apart (cohesion), fuse with another object (boundedness), or change size, shape, pattern, or color. Thus, a wooden spoon cannot spontaneously disappear, pass through a table, break apart, fuse with a pot, or change into a noodle; all of these events represent persistence violations. (Of course, a wooden spoon could be painted red, burned, sawed into pieces, or glued to a pot; such events represent *object transformations* rather than persistence violations, because in each case there is a causal mechanism responsible for the change effected; e.g., Gelman, Bullock, & Meck, 1980; Goswami & Brown, 1990; Needham & Baillargeon, 1997; Tzelnic, Kuhlmeier, & Hauser, 2009).

Basic Information

When building a physical representation for an event, the PR system first represents the *basic* information about the event (see figure 1.8). This basic information includes both identity and spatio-temporal information. The *identity* information provides broad categorical descriptors for the objects in the event: in particular, it specifies whether the objects are inert or self-propelled, human or non-human, and closed or open (i.e. open at the top to form a container, open at the bottom to form a cover, or open at both ends to form a tube; e.g., Bonatti, Frot, Zangl, & Mehler, 2002; Hespos & Baillargeon, 2001b; Luo, Kaufman, & Baillargeon, 2009; Wang et al. 2005; Wu & Baillargeon, 2008; Yuan & Baillargeon, 2008). The *spatio-temporal* information specifies the spatial arrangement of the objects and how it changes as the event unfolds (e.g., Kestenbaum, Termine, & Spelke, 1987; Quinn, 2007; Slater, 1995; Yonas & Granrud, 1984).

Both the identity and the spatio-temporal information about an event help specify how many objects are involved in the event. For example, if a human disappears behind a large screen and a non-human object appears from behind it, the identity information will specify that two distinct objects are involved in the event, one human and one non-human (Bonatti et al., 2002; Wu & Baillargeon, 2008). Similarly, if two identical objects stand apart on an apparatus floor and a screen is then lifted to hide them, the

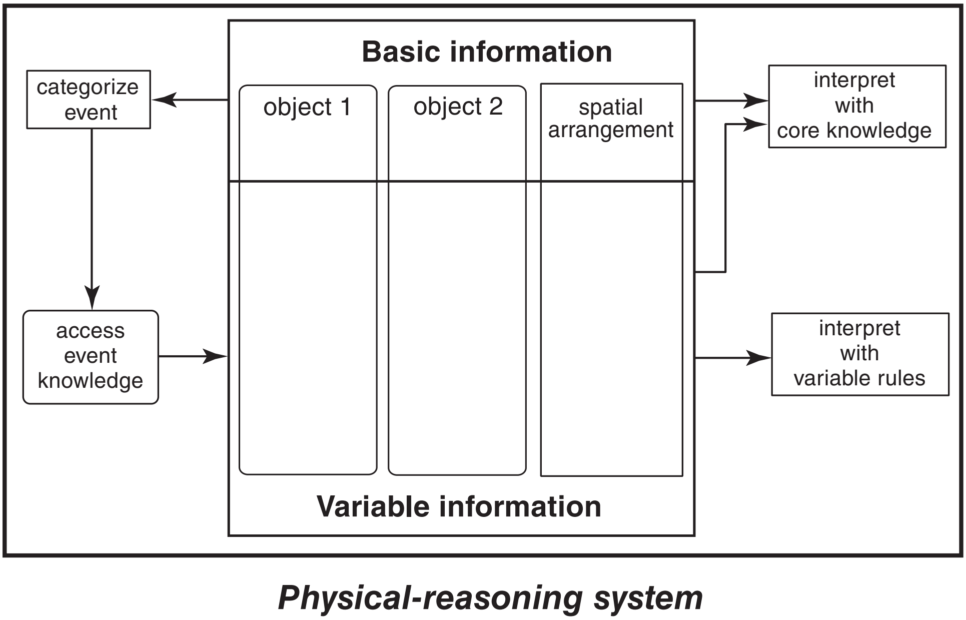

Figure 1.8 Schematic model of the physical-reasoning system: how infants represent and interpret the basic and the variable information about a physical event

spatio-temporal information will specify that two objects are present behind the screen (Aguiar & Baillargeon, 1999; Xu & Carey, 1996).

The PR system uses the identity and the spatio-temporal information about an event to *categorize* the event and to assign appropriate *roles* to the objects in the event (e.g., Leslie & Keeble, 1987; Onishi, 2009). Consider a simple event involving two identical blocks, block A and block B. If block A is used to hit block B, the event is categorized as a collision event, with block A as the hitter and block B as the object that is hit. If block B is lowered behind block A, the event is categorized as an occlusion event, with block A as the occluder and block B as the occluded object. After watching one of these events repeatedly, infants look reliably longer if the two objects change roles (e.g., if block A becomes the object that is hit in the collision event or the occluded object in the occlusion event).

The basic information about an event thus captures its essence: it specifies how many objects are involved in the event (e.g., two objects), what kinds of objects they are (e.g., inert, non-human, closed objects), what kind of event the objects are engaged in (e.g., a collision event), and what role each object plays in the event (object A is the hitter, object B is the object that is hit). (Note that, in our example, a simple sentence such as "It hit it" would map fairly well onto the basic description of the event, raising interesting questions about the links between language and basic event representations; for a discussion of structure-mapping between sentences and event representations in early language acquisition, see Fisher, 1996; Fisher, Gertner, Scott, & Yuan, in press).

Detecting basic persistence violations

In the first weeks of life, the PR system typically includes only basic information in its physical representation of an event. Although very limited, this information is nevertheless sufficient, when interpreted by the PR system's causal framework, to allow infants to detect several physical violations (e.g., Aguiar & Baillargeon, 1999; Baillargeon, 1987; Hespos & Baillargeon, 2001b; Lécuyer & Durand, 1998; Luo & Baillargeon, 2005; Spelke et al., 1992; Wang et al., 2005; Wilcox et al., 1996). These include the violations shown in figure 1.1 as well as those (from more recent experiments) shown in figure 1.9.

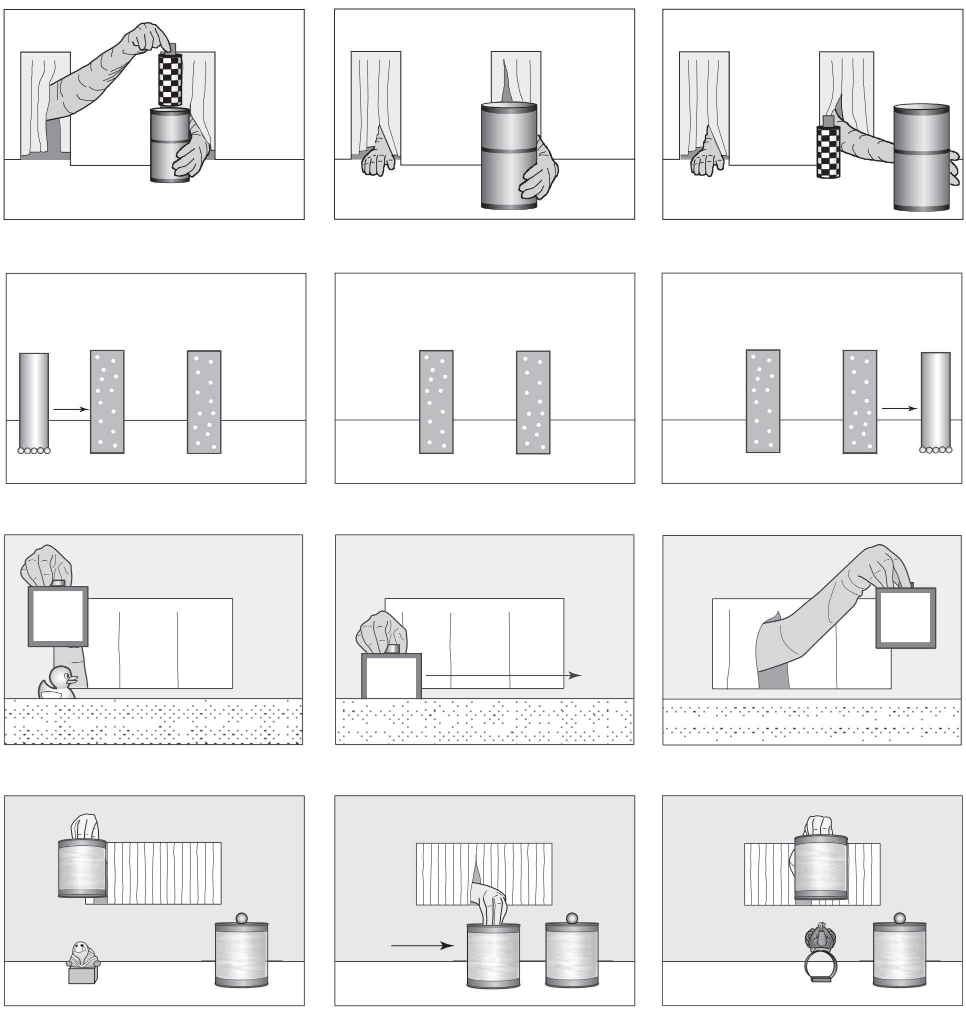

Figure 1.9 Examples of basic persistence violations that young infants are able to detect, as shown by Hespos and Baillargeon (2001b), Luo and Baillargeon (2005), Wang et al. (2005), and Wu et al. (2009b)

Focusing on the latter violations, 2.5- to 3-month-olds (the youngest infants tested successfully to date with the VOE method) are surprised when an object is lowered inside an open container which is then slid forward and to the side to reveal the object standing in the container's initial position (Hespos & Baillargeon, 2001b); when an object disappears behind one screen and then reappears from behind another screen without appearing in the gap between them (Luo & Baillargeon, 2005); when a cover is lowered over an object, slid to the side, and then lifted to reveal no object (Wang et al., 2005); and when a cover is lowered over a closed object, slid to the side, and then lifted to reveal an open object (Wu, Li, & Baillargeon, 2009).

All of these violations can be detected by very young infants because they involve only basic information (this is why we refer to them as *basic persistence violations*). In each case, the PR system represents the basic information about the event, applies the persistence principle to this information, and flags the event as a persistence violation. For example, consider once again the finding that infants are surprised when a cover is lowered over an object, slid to the side, and then lifted to reveal no object (Wang et al., 2005). As the event unfolds, the basic information represented by the PR system will include the following: (a) a cover is lowered over a closed object (the persistence principle will specify that the object continues to exist under the cover); (b) the cover is slid to the side (the persistence principle will specify that the object cannot pass through the sides of the cover and hence must have been displaced with the cover to its new location); and (c) the cover is lifted to reveal no object (the persistence principle will signal that a violation has occurred: the object should have been revealed when the cover was lifted).

Variable Information

We have just seen that, in the first few weeks of life, the PR system typically includes only basic information in its physical representation of an event. Although this information captures essential elements, it is still very limited. If a spoon is placed inside a pot, for example, the basic information will specify that an inert, non-human, closed object has been placed inside an inert, non-human, container. If a ball is placed on a block, the basic information will specify that an inert, non-human, closed object has been released in contact with another inert, non-human, closed object. In each case, the basic information thus leaves out many details: in particular, it does not specify the size, shape, pattern, or color of the objects, nor does it specify (in the second example) whether the ball is released on the top or against the side of the block. This more detailed information about the properties and arrangements of objects constitutes what we have termed *variable* information, and it is not included in physical representations until infants learn, with experience, that it is helpful for interpreting and predicting outcomes.

As infants observe physical events, they form distinct *event categories* (e.g., Aguiar & Baillargeon, 2003; Casasola, Cohen, & Chiarello, 2003; Hespos & Baillargeon, 2006; McDonough, Choi, & Mandler, 2003; Quinn, 2007; Wilcox & Chapa, 2002). For each category, infants identify *variables* that enable them to better interpret and predict outcomes (e.g., Aguiar & Baillargeon, 2002; Baillargeon, Needham, & DeVos, 1992; Hespos

& Baillargeon, 2008; Kotovsky & Baillargeon, 1998; Sitskoorn & Smitsman, 1995; Wang, Kaufman, Baillargeon, 2003; Wilcox, 1999). A variable both calls infants' attention to a certain type of information in an event (e.g., features of objects or their arrangements) and provides a causal rule for interpreting this information. To illustrate, by about 12 months of age, most infants have identified height as a relevant variable in covering events: when a cover is placed over an object, infants now attend to the relative heights of the cover and object. As a result, 12-month-olds look reliably longer if a tall object becomes fully hidden under a short cover (Wang et al., 2005); they look reliably longer if a short object is much taller after being briefly hidden under a tall cover (Wang & Baillargeon, 2006); and they are reliably more likely to search for a tall object under a tall as opposed to a short cover (Wang & Kohne, 2007). In contrast, infants younger than 12 months typically fail all of these tasks (Wang & Baillargeon, 2006; Wang & Kohne, 2007; Wang et al., 2005).

With the gradual identification of variables, infants' physical representations become increasingly richer (see figure 1.8). After representing the basic information about an event and using this information to categorize the event, the PR system accesses the list of variables that have been identified as relevant for predicting outcomes in the category selected. The PR system then gathers information about each variable and includes this information in the physical representation of the event. This variable information is then interpreted by the variable rules as well as by the PR system's causal framework.

To illustrate this process, consider what variable information 7.5-month-olds would include in their physical representation of a containment event in which a ball was lowered inside a box. By 7.5 months, width and height have typically been identified as containment variables, but container-surface and color have not (see figures 1.2, 1.5, and 1.6). Thus, infants should include information about the relative widths and heights of the ball and box in their physical representation of the event, but not information about the container's surface (e.g., whether it is transparent) or about the ball's color. As a rule, the PR system does not include information about variables that have not yet been identified in its physical representation of an event.

Detecting variable persistence violations

As may be obvious from the preceding description, infants can detect a persistence violation involving a specific variable (or a *variable persistence violation*) only if the PR system includes information about the variable in its physical representation of the event. Figures 1.3 to 1.7 present many examples of variable persistence violations that infants fail to detect because they have not yet identified the relevant variables and hence do not include the necessary information in their physical representations of the events. For instance, infants cannot be surprised if an object surreptitiously changes shape, pattern, or color when briefly hidden behind a narrow screen (Wilcox, 1999) or inside a small container (Ng & Baillargeon, 2009) if they do not include shape, pattern, and color information in their physical representations of the events (see figures 1.4 and 1.5). In the first year of life, whether a given variable persistence violation is detected will depend primarily on whether (a) the variable has been identified for the event category involved, and hence (b) information about the variable is included in the physical representation of the event.

The present account also helps explain the striking décalages discussed earlier in infants' VOE responses (see figures 1.5 and 1.7). In each case, the PR system will first represent the basic information about the event, categorize the event, and access the list of variables identified for the category. If height has been identified as a relevant variable for the category selected (e.g., a containment event), then height information will be included in the physical representation of the event, and violations involving this information will be detected. Conversely, if height has not yet been identified as a relevant variable for the category selected (e.g., a tube event), then height information will not be included in the physical representation of the event, and violations involving this information will obviously not be detected.

The same constraints apply to infants' responses in action tasks. Infants who have identified height as a containment variable will spontaneously attend to the heights of objects and containers and thus will search for a tall object inside a tall as opposed to a short container (see figure 1.6). In contrast, infants who have not yet identified height as a containment variable will fail to include height information in their physical representations and therefore will search for a tall object inside either a tall or a short container (Hespos & Baillargeon, 2006).

Identifying Variables: The Explanation-Based Learning Process

We suggested earlier that infants learn, with experience, what variables are helpful for interpreting and predicting outcomes in each event category. How does this learning process take place? Building on work in machine learning by DeJong (1993, 1997), we have proposed that the identification of a variable depends on an *explanation-based learning* (EBL) process that involves three main steps (e.g., Baillargeon et al., 2006; Baillargeon et al., 2009; Wang & Baillargeon, 2008a).

First, infants must notice *contrastive outcomes* relevant to the variable. This occurs when infants build similar physical representations for two or more events – and notice that the events have contrastive outcomes. For example, consider the variable height in covering events, which is typically identified at about 12 months of age (e.g., Wang et al., 2005; Wang & Kohne, 2007). We suppose that at some point prior to 12 months of age, infants begin to notice – as they manipulate covers and objects or as they observe others doing so – that when a cover is lowered over an object, the object sometimes remains partly visible beneath the cover and sometimes does not. Infants thus notice contrastive outcomes they cannot predict based on their current variable knowledge: similar physical representations ("cover lowered over object") lead to contrastive outcomes ("object remains partly visible beneath cover" versus "object becomes fully hidden"), suggesting that a crucial piece of information is missing from the representations.

At this point, infants begin to search for the *conditions* that map onto these contrastive outcomes. Specifically, infants attempt to determine under what condition one outcome is observed, and under what condition the other outcome is observed. Eventually, infants uncover a regularity linking each outcome with a distinct condition (we assume that infants' statistical learning mechanisms play a key role in detecting these regularities; e.g., Fiser & Aslin, 2002; Saffran, 2009). In the case of the variable height in covering events, infants detect that objects remain partly visible when placed under covers that are shorter than the objects, and become fully hidden when placed under covers that are as tall as or taller than the objects.

Finally, and most critically, infants attempt to generate an *explanation* for the condition–outcome regularity they have observed, based on their prior knowledge. According to the EBL process, *only* condition–outcome regularities for which explanations can be provided are recognized as new variables. These explanations are typically very limited and shallow (e.g., Keil, 1995; Luo et al., 2009; Wilson & Keil, 2000), but they still serve to integrate new variables with infants' existing causal knowledge (by the same token, explanations also prevent infants from learning incorrect or spurious variables). In the case of the variable height in covering events, infants' principle of persistence can provide a ready explanation for their observations: because an object continues to exist and retains its height when under a cover, it can become fully hidden only if its height is equal to, or shorter than, that of the cover.

After a new variable has been identified (i.e. is added to the list of variables relevant to an event category), infants begin to routinely include information about the variable in their physical representations of events from the category.

The EBL process thus helps make clear why infants learn separately about each event category. Infants do not compare arbitrary groups of events and look for invariants or critical variables that might explain similarities or differences among the events. The only situation that can trigger the identification of a variable is one where events with similar physical representations yield (as yet unpredicted or unexplained) contrastive outcomes. The learning process is thus highly constrained: it is designed to compare apples with apples, and not apples with rabbits or spoons.

Teaching experiments

The EBL process predicts that infants who have not yet identified a variable in an event category should be able to identify the variable – even several months before they would normally do so – if exposed in the laboratory (or the home) to appropriate observations for the variable. And indeed, a number of "teaching" experiments have now provided evidence for this prediction (e.g., Baillargeon, 2002; Wang & Baillargeon, 2008a; Wang & Kohne, 2007).

For example, in a recent series of experiments, Wang and her colleagues "taught" 9-month-old infants the variable *height* in covering events (recall that this variable is typically not identified until about 12 months of age; Wang & Baillargeon, 2006; Wang et al., 2005). Infants received three pairs of teaching trials. In each pair of trials, a tall and a short cover (that differed only in height) were lowered over a tall object; infants could see that the object remained partly visible beneath the short cover, but became fully hidden under the tall cover. Different covers were used in the three pairs of teaching trials. Following these trials, the infants received either a VOE or an action task involving novel covers and objects. In the VOE task, infants looked reliably longer (even after a 24-hour delay) when a tall object became fully hidden under a short as opposed to a tall cover (Wang & Baillargeon, 2008a; see figure 1.10). In the action task, infants

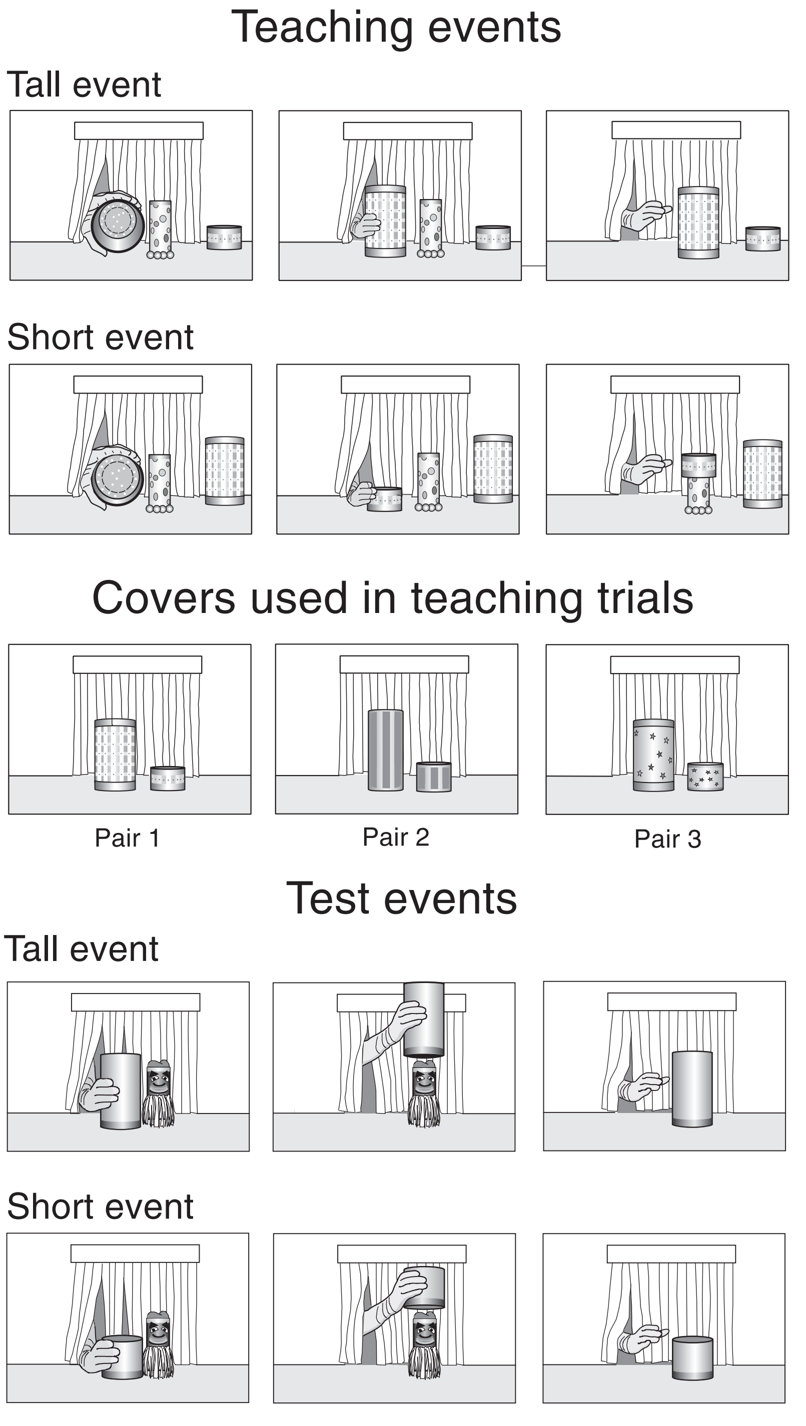

Figure 1.10 Teaching and test events used in Wang and Baillargeon (2008a)

searched correctly for a tall object under a tall as opposed to a short cover (Wang & Kohne, 2007).

From an EBL perspective, these results are readily interpretable. During the teaching trials, (a) the infants noticed that events with similar physical representations led to contrastive outcomes; (b) they uncovered the specific height conditions that mapped onto these outcomes; and (c) they built an explanation for this condition–outcome regularity using their prior knowledge. Height was then added to the list of variables identified as relevant to covering events. When the infants next encountered covering events, they attended to the height information in the events, which enabled them to detect the violation in the VOE task and to search correctly in the action task.

Two additional results supported this analysis. First, infants failed at the VOE task (indicating that they did not identify height as a covering variable) if they received inappropriate teaching trials for which no explanation was possible (Wang & Baillargeon, 2008a; see also Newcombe, Sluzenski, & Huttenlocher, 2005). In this experiment, false bottoms were inserted into the teaching covers, rendering them all 2.5 cm deep; when the covers were rotated forward to reveal their interiors, the infants could notice that they were all shallow. Thus, in each pair of teaching trials, the infants still observed that the tall object became fully hidden under the tall cover and partly hidden under the short cover – but they could no longer build an explanation for this condition–outcome regularity, because the tall and short covers were now equally shallow (i.e. it did not make sense that the tall object became fully hidden under the tall but shallow covers). Second, infants failed at the action task if they received appropriate teaching trials but were tested with tubes instead of covers (Wang & Kohne, 2007). When the tops of the tall and short covers were removed to form tubes, infants searched for the tall object in either the tall or the short tube, suggesting that they had identified height as a variable relevant to covering events and did not generalize this variable to tube events.

Together, the results summarized in this section suggest that infants can be taught a new variable in an event category through brief exposure to appropriate observations for the variable. Furthermore, infants who are taught a new variable immediately attend to information about the variable in situations presenting different stimuli and calling for different responses – but only when these situations involve events from the *same* category. The EBL process ensures broad, yet circumscribed, generalization: a variable identified in an event category is attended to in *any* event from the category – but *only* in events from the category.

A Three-System Account

In the previous section, we presented an account of how the PR system operates and reviewed some of the research supporting this account (for a detailed review, see Baillargeon et al., 2009). As a result of this research, we now have a clearer idea of what basic and variable information infants are likely to represent when watching a physical event, and how this information is likely to guide their responses in VOE and action tasks.

In this section, we begin to look *beyond* the PR system and consider how it relates to two other systems that have received a great deal of attention in the infant and adult visual cognition literature: the *object-tracking (OT) system* and another system that we have termed the *object-representation (OR) system* (e.g., Wang & Baillargeon, 2008b). Below, we first discuss these two systems and then describe new experiments that test possible links between the PR and the OR systems.

This is a truly exciting time in the field of infant cognition, as developments in different subfields are coming together to paint a much more detailed picture of the cognitive architecture that underlies infants' responses to physical events.

Object-Tracking System

Consider a simple situation in which infants see two objects standing apart on an apparatus floor. The object-tracking (OT) system assigns an index to each object, based on the available spatio-temporal information; because the objects occupy different locations in space, they are readily perceived as separate objects (e.g., Leslie, Xu, Tremoulet, & Scholl, 1998; Pylyshyn, 1989, 1994; Scholl & Leslie, 1999). Each index functions as an index finger or attentional pointer that "sticks" to its object as it moves, enabling infants to keep track of the object (i.e. to know where it is without having to search for it).

There is a sharp limit to the number of objects infants can track simultaneously. Initially, this limit was thought to be about three objects overall (e.g., Leslie et al., 1998; Scholl & Leslie, 1999), but seminal experiments by Feigenson and her colleagues have revealed that three is actually the limit *per set* of objects. In experiments using a manual search task (e.g., Feigenson & Carey, 2003, 2005; Feigenson & Halberda, 2004), for example, 12- to 14-month-olds were presented with a large box; in the front of the box was a spandex-filled opening with a slit (this arrangement made it possible for infants to reach into the box, but not to see into it). In each trial, an experimenter first placed objects such as balls on top of the box and then hid them inside the box; the infant was then allowed to search for the balls. Across trials, the researchers compared whether infants were more likely to continue searching when only some of the balls had been retrieved than when all of the balls had been retrieved. Results indicated that infants searched correctly when three but not four balls were hidden, suggesting that they could not keep track of more than three objects at a time. However, additional results indicated that infants could overcome this limit and search successfully when four and even six objects were hidden, as long as the objects were presented in spatially distinct subsets prior to hiding (Feigenson & Halberda, 2004, 2008). Thus, although 14-month-olds failed to search correctly when a single set of six balls was placed on top of the box at the start of the trial, they succeeded when the six balls were grouped into three spatially distinct sets of two balls. These results suggest that, in infancy, the OT system can simultaneously track as many as three sets of objects, provided that each set contains no more than three objects.

Object-Representation System

Let us return to our simple situation in which infants see two objects standing apart on an apparatus floor. As soon as the OT system assigns an index to each object, the object-representation (OR) system begins to build a detailed representation of each object, listing both individual (e.g., color) and relational (e.g., relative height) features (e.g., Huttenlocher, Duffy, & Levine, 2002; Kahneman, Treisman, & Gibbs, 1992; Needham, 2001; Rose, Gottfried, Melloy-Carminar, & Bridger, 1982). We assume that, under simple conditions, each object's representation is linked to its index, so that infants can keep track of which features belong to which object (e.g., Káldy & Leslie, 2003, 2005; Mareschal & Johnson, 2003; Oakes, Ross-Sheehy, & Luck, 2006).

A variety of segregation, recognition, and categorization processes can operate on the representations in the OR system, to highlight particular information or to include additional information (e.g., Feigenson & Halberda, 2008; Needham, 2001; Needham, Cantlon, & Ormsbee Holley, 2006; Needham, Dueker, & Lockhead, 2005). To illustrate, consider a situation in which two objects stand side by side (instead of apart) on an apparatus floor. Because the OT system relies primarily on spatio-temporal information, it will treat this *adjacent display* as a single object and will therefore assign a single index (e.g., Kestenbaum et al., 1987; Needham, 2000). However, if the OR system can determine that the display contains two separate objects, then (via communication between the OR and the OT systems) a second index will be assigned.

Experiments by Needham and her colleagues indicate that, beginning at 3–4 months of age, infants can sometimes use shape information to correctly segregate an adjacent display (e.g., Needham, 1998, 1999, 2000; for a review, see Needham, 2009). If infants cannot use shape information to parse the display (e.g., because the objects' shapes are too difficult for them to encode), they can still succeed if they recognize one of the objects in the display as one they have encountered previously (e.g., Needham, 2001; Needham & Baillargeon, 1998), or as one from a familiar object category (e.g., Needham et al., 2006). If neither object in the display is familiar or belongs to a familiar category, infants may still correctly parse the display if they are first induced to form a relevant category (e.g., Dueker, Modi, & Needham, 2003; Needham et al., 2005). In a seminal series of experiments, 4.5-month-olds were presented with an adjacent test display composed of a curved yellow cylinder and a tall blue rectangular block decorated with small white squares. Infants succeeded in parsing this display if they were briefly familiarized with a static array of three blocks that were similar in size and shape to the test block but differed in color and pattern. These results suggested that the infants (a) formed a category when shown the three familiarization blocks; (b) recognized that the test block was a novel exemplar of this category; and (c) perceived the cylinder and block in the test display as two separate objects.

Together, these results suggest that, when infants first see objects on an apparatus floor, they not only represent (many of) the features of each object, but they spontaneously engage in various processes including segregation, recognition, and categorization.

Physical-Reasoning System

Consider a simple situation in which infants see two distinct objects, a container and a block, standing apart on an apparatus floor (see figure 1.11). As infants attend to the

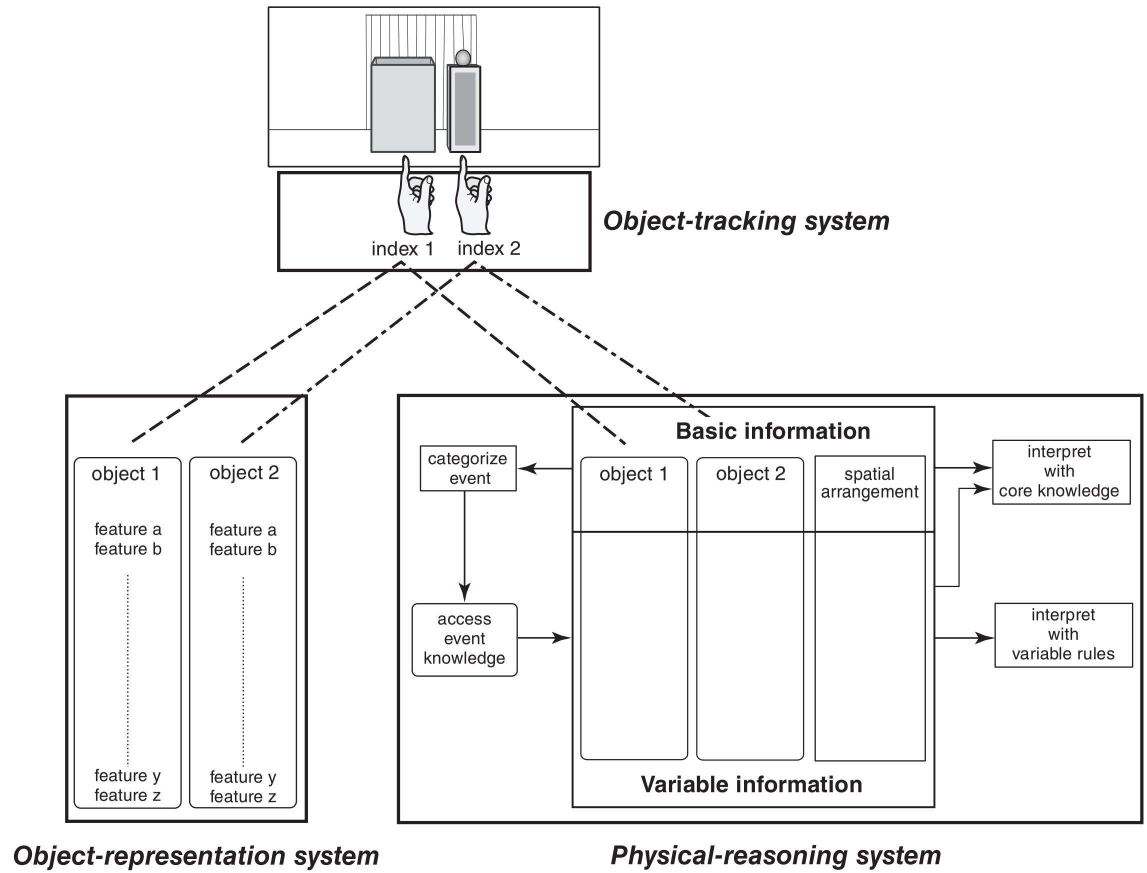

Figure 1.11 Schematic model of the object-tracking, object-representation, and physical-reasoning systems. The physical-reasoning system becomes involved when the objects interact (e.g., when an experimenter's hand lifts the block and lowers it inside the container)

objects, the OT system assigns an index to each object, and the OR system builds detailed representations of the objects. If an experimenter then places the block inside the container, the PR system also becomes involved: the objects are now engaged in an interaction, and the PR system's main purpose is that of interpreting and predicting the outcomes of such interactions.

As was explained previously, the PR system builds a specialized physical representation of the event: it (a) represents the basic information about the event; (b) uses this information to categorize the event; (c) accesses the list of variables that have been identified as relevant for the event category selected; and (d) includes information about each variable in the event's physical representation. The basic and variable information about each object is linked to its index, so that infants can keep track of the objects as they move and interact. Finally, the information included in the physical representation of the event is interpreted using the PR system's core knowledge and the applicable variable rules.

Dissociation between the OR and PR Systems

One striking consequence of the three-system account just outlined is that separate object representations are formed in the OR and PR systems, *with the OR representations often including information that is not included in the PR representations* (e.g., Gertner et al., 2009; Li, Baillargeon, & Simons, 2009; Wang & Baillargeon, 2008b; Wang & Mitroff, 2009; for related results with adults, see Simons, Chabris, Schnur, & Levin, 2002). To illustrate, consider once again the simple event depicted in figure 1.11. Although information about the color and height (say) of the container and block would typically be included in the OR system (e.g., Huttenlocher et al., 2002; Needham, 2001), this information would be included in the PR system *only* if infants had already identified color and height as containment variables (see figure 1.5). Thus, object information that is routinely included in the OR system may not be included in the PR system if the relevant variables have not yet been identified for the event category involved.

Why should the OR and PR systems be set up in this way? Why not have *all* of the object information in the OR system *also* included in the PR system? The answer to these questions, we suspect, mainly has to do with learnability. As we saw previously, in the first few weeks of life, the PR system builds very sparse physical representations that include only basic information; representations become gradually richer as infants learn, category by category and variable by variable, what information is causally relevant for predicting outcomes. If infants included from the start all of the object information from the OR system in their physical representations, they might have great difficulty sorting through all of that information to figure out what was helpful for predicting what. These learnability considerations loom even larger when one considers that (a) infants have limited information-processing resources and (b) the PR system (like the language-processing system, for example) must operate rapidly, online, as events unfold. Speed is critical: time spent sorting through irrelevant information is time ill-spent. To make sense of events as they occur in the world, infants must be able to keep up with them. Beginning with sparse blueprints and filling in additional information as it proves useful is thus a highly adaptive learning strategy.

Retrieving Object Information from the OR System

If separate object representations exist in the OR and PR systems, then it might be possible for the PR system to *query* the OR system for information about a variable when this information can no longer be gathered from inspection of the scene (e.g., because objects have become hidden). In other words, the OR system might serve as a generous neighbor who readily “passes on” object information when queried by the PR system (see figure 1.12).

To test this suggestion, we recently carried out an experiment with 6-month-olds (Li et al., 2009). This experiment examined infants’ ability to detect a surreptitious change to the height of an object, and it built upon the findings that the variable height is identified at about 3.5 months in occlusion events, but only at about 7.5 months in containment events (e.g., Baillargeon & DeVos, 1991; Hespos & Baillargeon, 2001a). The infants were assigned to one of three conditions (see figure 1.13): an occlusion, a containment, and a no-event condition. We assumed that the occlusion and the containment conditions would involve both the OR and the PR systems, and that the no-event condition would involve only the OR system.

The infants in the *occlusion* condition received one trial presented in three successive “snapshots”; between snapshots, a large panel hid the interior of the apparatus. In snapshot 1 (which lasted about 5 s), a tall container stood next to a tall rectangular block with a knob at the top; the rectangular portion of the block was about the same height as the container. In snapshot 2 (which lasted about 4 s), an experimenter’s gloved hand held the block *behind* the container, above the apparatus floor, and twisted it gently; only the knob and the very top of the block were visible, so that the infants could not determine the block’s exact height. In snapshot 3, the block again stood next to the container, and was either the same height as before (no-change event) or much shorter (change event). Snapshot 3 lasted until the infant looked away and the trial ended.

We reasoned that, during snapshot 1, the OT system would assign an index to the container and block, and the OR system would form detailed representations of the objects, including their relative heights. During snapshot 2, the PR system would represent the basic information about the event, would categorize it as an occlusion event, and would access the list of variables identified as relevant for occlusion events. At 6 months of age, this list would include the variable height; although the infants could determine the container’s height by inspecting the scene, they could not determine the block’s height. At this point, the PR system would query the OR system for information about the relative heights of the container and block. The OR system would supply this information, which would become included in the PR system, allowing the infants to detect the change to the block’s height in the change event. We thus predicted that, in the occlusion condition, the infants who saw the change event would look reliably longer than those who saw the no-change event.

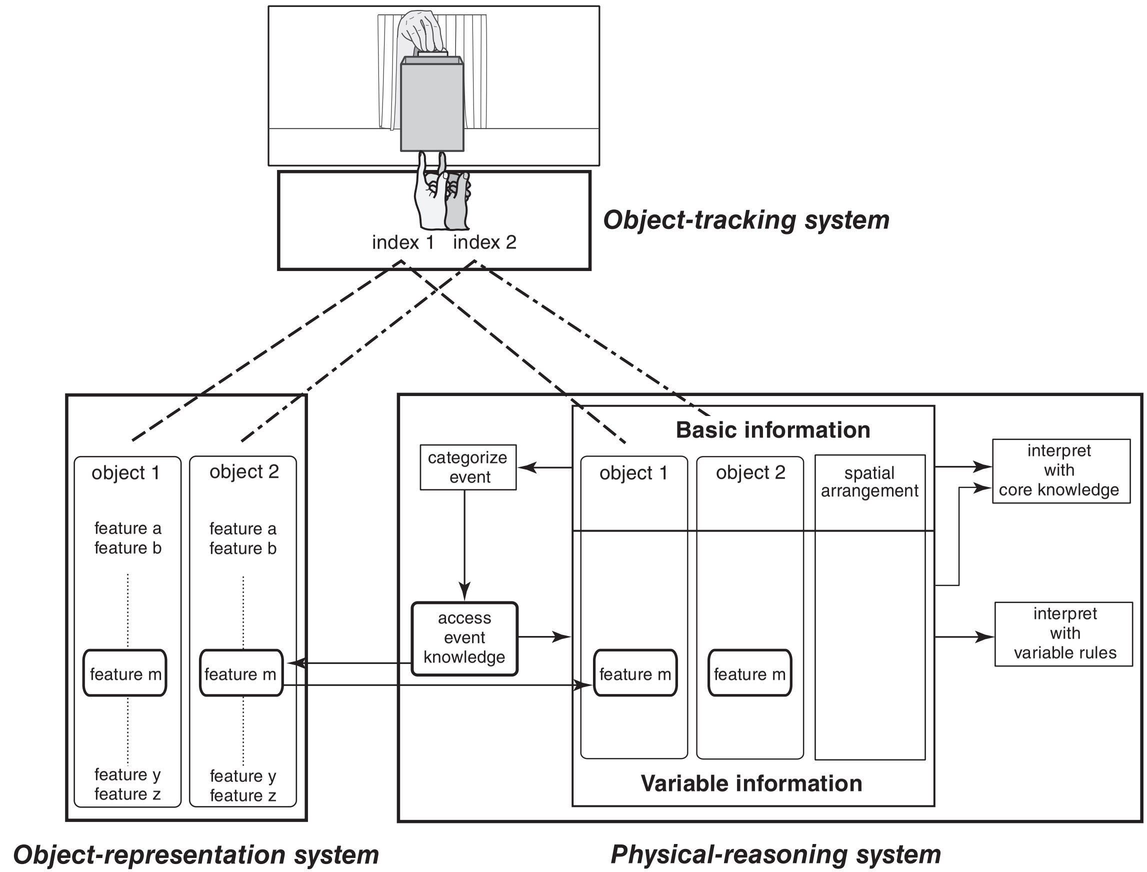

Figure 1.12 Schematic diagram of the retrieval of object information from the object-tracking system by the physical-reasoning system

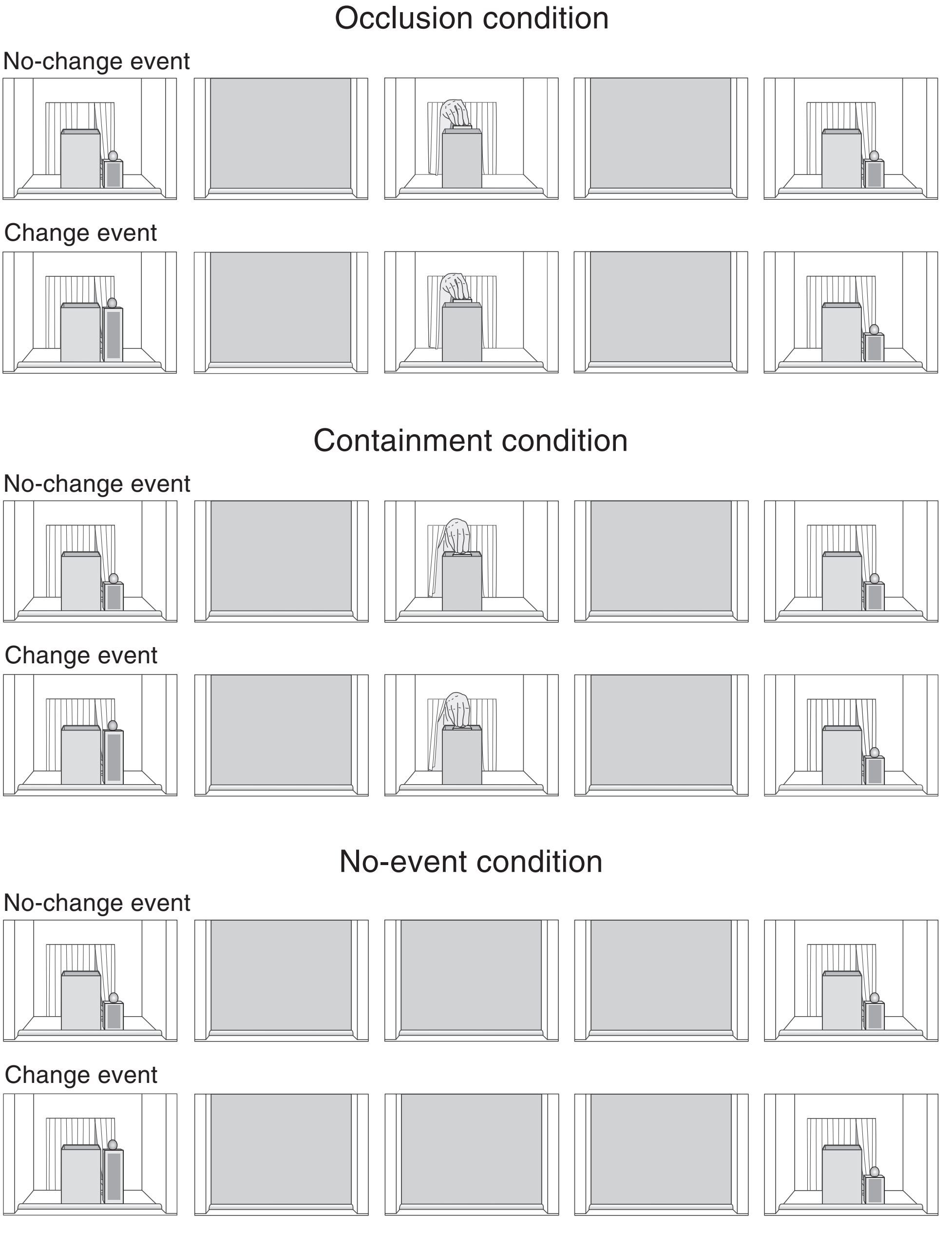

Figure 1.13 Test events used in the occlusion, containment, and no-event conditions of Li et al. (2009)

The infants in the *containment* condition received a similar trial except that in snapshot 2 the hand held the block *inside* the container, above its bottom surface; as before, the infants could not determine the block's exact height. Because at 6 months height has not yet been identified as a containment variable, we expected that the PR system would *not* query the OR system for information about the relative heights of the container and block. As a result, no height information would be included in the PR system, and the infants should fail to detect the violation in the change event. We thus predicted that, in the containment condition, the infants would look about equally whether they saw the change or the no-change event.

Finally, the infants in the *no-event* condition again received a similar trial, except that the panel remained shut throughout snapshot 2. We reasoned that, in snapshot 3, the OR system should readily detect that the block was no longer as tall as the container (after all, the no-event condition amounted to a simple recognition task). Interestingly, prior findings from the infant recognition literature suggested that, in the no-event condition, the infants would show the opposite pattern from that predicted in the occlusion condition. According to this prior research, infants presented with static visual stimuli typically show a *familiarity* preference under shorter familiarization conditions, and a *novelty* preference under longer familiarization conditions (e.g., Hunter & Ames, 1988; Hunter, Ross, & Ames, 1982; Rose et al., 1982). According to Rose et al. (1982), "as infants begin to process a stimulus, they prefer to look at that which is familiar; once processing is more advanced, their preference shifts to that which is novel" (p. 711). It seems adaptive that the OR system would be designed in this way, and that infants whose processing of an object is interrupted would "give priority to . . . consolidating information they are in the process of acquiring before moving on to make new discoveries" (Hunter et al., 1982, p. 528; see also Bauer, 2009). To return to our no-event condition, since snapshot 1 was very brief, we expected that the infants who saw the no-change event would look reliably longer than those who saw the change event.

Results were as predicted: in the occlusion condition, the infants who saw the change event looked reliably longer than those who saw the no-change event; in the containment condition, the infants looked about equally at the two events; and in the no-event condition, the infants who saw the no-change event looked reliably longer than those who saw the change event. These results provide strong support for our claim that separate object representations are formed in the OR and the PR systems, and that the PR system can query the OR system for information about a variable.

More generally, these results provide two pieces of evidence that the OR and PR systems constitute distinct systems with distinct signatures. First, the contrasting results of the no-event and containment conditions suggest that object information can be represented in the OR system and yet not be available to the PR system: the infants in the no-event condition detected the change to the block's height, but those in the containment condition did not. Second, the contrasting results of the no-event and occlusion conditions indicate that the OR and PR systems may respond differently to similar situations: although the infants in both conditions gave evidence that they detected the change to the block's height, they did so in different ways. In the no-event condition, the infants looked longer at the *familiar* block, as though they sought to complete or consolidate its representation. In contrast, the infants in the occlusion condition looked longer at the *novel* block, as though they were attempting to make sense of this persistence violation.

Concluding Remarks: We Have Come a Long Way!

As we saw at the start of this chapter, the questions that dominated investigations of infants' physical knowledge 25 years ago were broad questions such as whether infants realize that objects continue to exist when hidden. Today, as illustrated by the experiment discussed in the last section (Li et al., 2009), questions have become far more targeted and precise. We know a great deal more about what basic and variable information infants include in their physical representations of events and about how they interpret this information. We are discovering more and more ways of enhancing the information that infants represent about events, through teaching and other contextual manipulations (e.g., Feigenson & Halberda, 2008; Gertner et al, 2009; Li & Baillargeon, 2009; Wang & Baillargeon, 2005; Wang & Kohne, 2007; Wilcox & Chapa, 2004; Wilcox & Woods, 2009; Xu, 2002). Finally, we are beginning to understand the various cognitive systems that underlie infants' responses to events, and we are exploring the dynamic interplay between these systems.

Note

1 Young infants recognize that not all changes that occur while an object is briefly occluded are impossible changes (Wu, Baillargeon, & Gelman, 2009). In a series of experiments, 5-month-olds were first introduced to a novel self-propelled object with one or two prominent parts attached to its "body." In the test events, the object was briefly hidden by a screen; when the screen was removed, the object either was the same as before (no-change event) or had undergone some change (change event). This change was a change either in appearance (e.g., a jagged "tail" changed into a half-circle), in location (e.g., an "arm" moved from the left to the right side of the object's body), or in orientation (e.g., the object's "tail" changed from a horizontal to a vertical orientation). Infants detected a violation when the object's parts changed appearance or location, but not when they changed orientation (infants did view orientation changes as impossible, however, when the object was inert rather than self-propelled). By 5 months of age, infants thus believe that a self-propelled object can use its internal energy to reorient its parts, but not to alter their appearance or to reattach them at new locations.

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