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Innate Ideas Revisited For a Principle of Persistence in Infants' Physical Reasoning

Renée Baillargeon
University of Illinois at Urbana-Champaign

Abstract

The notion of innate ideas has long been the subject of intense debate in the fields of philosophy and cognitive science. Over the past few decades, methodological advances have made it possible for developmental researchers to begin to examine what innate ideas—what innate concepts and principles—might contribute to infants' knowledge acquisition in various core domains. This article focuses on the domain of physical reasoning and on Spelke's (1988, 1994) proposal that principles of continuity and cohesion guide infants' interpretation of physical events. The article reviews recent evidence that these two principles are in fact corollaries of a single and more powerful principle of persistence, which states that objects persist, as they are, in time and space.

Is an infant's knowledge about the physical world derived solely from the application of domain-general processes to experience? Or does it also reflect the contribution of *innate ideas*—concepts and principles specific to the domain of physical reasoning that guide an infant's interpretation of physical events from birth?

The notion of innate ideas, first introduced by Plato, was developed extensively in the 17th century by rationalist philosophers such as René Descartes and Gottfried Wilhelm Leibniz. They proposed that some ideas are part of our rational nature and that although experience may be necessary to bring them to consciousness, it does not determine their form. These proposals were criticized by empiricist philosophers such as John Locke in the 17th century, David Hume in the 18th century, and John Stuart Mill in the 19th century. The empiricist thesis held that innate ideas were superfluous, because knowledge acquisition could be explained more parsimoniously in terms of the application of domain-general (and often species-general) processes to experience. Empiricist approaches prevailed in philosophy and psychology well into the 20th century: Consider, for example, the behaviorism of John B. Watson (1924) and B.F. Skinner (1938) or the constructivism of Jean Piaget (1954).

The notion of innate ideas was finally revived in the mid-20th century when the linguist Noam Chomsky (1965) proposed that human infants are born with a universal grammar that makes possible their rapid acquisition of language. Chomsky's theory departs from earlier rationalist proposals in at least two significant ways. First, the universal grammar is understood to be an unconscious language-acquisition system, rather than a set of ideas that can be brought to consciousness by appropriate triggers. Second, the system is construed as a biological adaptation whose existence is rooted in the process of evolution, rather than in metaphysics (for reviews, see Chomsky, 1965; Markie, 2004; Pinker, 2003; Samet, 1999).

Address correspondence to Renée Baillargeon, Department of Psychology, University of Illinois, 603 East Daniel Street, Champaign, IL 61820; rbaillar@uiuc.edu.

In the following decades, Chomsky's (1965) views were adopted by many (though by no means all) cognitive scientists. In the field of developmental psychology, methodological advances made it possible to begin to explore experimentally what innate concepts and principles might contribute to infants' knowledge acquisition in various domains, including physical reasoning, psychological reasoning, and number (e.g., Gergely, Nádasdy, Csibra, & Bíró, 1995; Leslie, 1987, 1994; Premack & Premack, 1995; Spelke, 1988; Wynn, 1992).

Within this body of developmental work, Elizabeth Spelke's proposal, that principles of *continuity* and *cohesion* guide infants' interpretation of physical events, has been highly influential (e.g., Spelke, 1988, 1994; Spelke, Breinlinger, Macomber, & Jacobson, 1992; Spelke, Phillips, & Woodward, 1995). The principle of continuity states that objects exist and move continuously in time and space: They cannot spontaneously appear or disappear (continuity), nor can they occupy the same space as other objects (solidity). The principle of cohesion states that objects are connected and bounded entities: They cannot spontaneously fragment as they move (cohesion) or fuse with other objects (boundedness).

Although this point is often misunderstood by empiricist researchers, claims about innate ideas are of course empirical, and as such they are subject to revision in light of new experimental findings. In this article, I review evidence suggesting that the principles of continuity and cohesion represent only two corollaries of a single and more powerful principle of *persistence*, which states that objects persist, as they are, in time and space.

CONTINUITY, COHESION, AND PERSISTENCE

Initial investigations of infants' physical reasoning revealed three main findings relevant to Spelke's proposal that infants interpret physical events in accordance with the principles of continuity and cohesion. First, infants succeeded in detecting several different continuity violations: They were surprised[1] when shown events in which objects magically disappeared or occupied space already occupied by other objects (e.g., Baillargeon, Spelke, & Wasserman, 1985; Spelke et al., 1992). Second, infants detected cohesion violations when shown events in which objects broke apart as they moved (e.g., Needham, 1999; Spelke, Breinlinger, Jacobson, & Phillips, 1993). Third, infants failed to detect several different change violations when shown events in which objects surreptitiously changed size, shape, pattern, or color (e.g., Newcombe, Huttenlocher, & Learmonth, 1999; Simon, Hespos, & Rochat, 1995).[2]

These findings led to the commonly held view that young infants expect objects to exist continuously and to remain cohesive, in accordance with the principles of continuity and cohesion, but that they have no expectation about objects' individual properties until they learn for each object category, which spontaneous changes are possible and which are not (e.g., Scholl & Leslie, 1999; Xu & Carey, 1996). In this view, infants' physical world is thus, in part, a fairy-tale one: Although cups can neither magically disappear nor break apart, they can spontaneously change into pumpkins.

[1]Infants are said to be surprised in violation-of-expectation tasks when they look longer at events that violate, as opposed to confirm, their expectations; the term *surprised* is thus used here simply as a shorthand descriptor to denote a state of heightened attention or interest induced by an expectation violation. For many years, researchers expressed concerns over the interpretation of violation-of-expectation findings, in part because of the gap between these findings and those of action tasks assumed to tap the same physical knowledge. Fortunately, these concerns have begun to dissipate as more sensitive action tasks have confirmed findings from violation-of-expectation tasks (e.g., Goubet & Clifton, 1998; Hespos & Baillargeon, 2006, in press; Hofstadter & Reznick, 1996; Hood & Willatts, 1986; Kochukhova & Gredeback, 2007; Li & Baillargeon, 2007; Ruffman, Slade, & Redman, 2005; von Hofsten, Kochukhova, & Rosander, 2007; Wang & Kohne, in press).

[2]If we define change violations as violations in which the properties of objects undergo spontaneous changes, then technically cohesion violations are also change violations. However, for clarity's sake, in this article I follow tradition and distinguish between cohesion and other change violations.

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Subsequent investigations cast doubt on this characterization of the infant's physical world: They revealed that infants could detect some continuity violations but not others and some change violations but not others (e.g., Hespos & Baillargeon, 2001a; Wilcox, 1999). To make sense of these conflicting findings—and to sort out the conditions in which infants do and do not detect continuity and change violations—my collaborators and I developed a new account of infants' physical reasoning (Baillargeon, Li, Luo, & Wang, 2006; Baillargeon, Li, Ng, & Yuan, in press).

Our account assumes that infants' representations of events—or physical representations—are initially impoverished but become richer with experience as infants gradually learn what information to include in order to better predict outcomes. Any information infants include in their physical representations becomes subject to a principle of persistence, which incorporates and extends the principles of continuity and cohesion. The persistence principle states that objects not only exist continuously and remain cohesive, they also retain their individual properties. According to this principle, no object can undergo a spontaneous or uncaused change in the course of an event, be it winking out of existence; breaking apart; or changing size, shape, pattern, or color. Of course, outside of the laboratory, objects rarely undergo such spontaneous changes, so an expectation of persistence is highly adaptive.

According to our account, infants succeed in detecting continuity and change violations when they have included the necessary information to do so in their physical representations. Thus, infants cannot be surprised when a wide object is lowered inside a narrow container (a continuity violation) or when a narrow object is much wider after being briefly lowered inside a wide container (a change violation) if they have included no width information in their physical representation of the event. Consistent with this analysis, infants who fail to detect a continuity or a change violation in an event, because they have not yet learned to include the necessary information in their physical representation of the event, succeed in detecting the violation if induced (through contextual manipulations) to represent the information. Once included in the physical representation, the information becomes subject to the persistence principle, and the event is flagged as a violation.

The preceding account suggests that the physical world of infants is not, in fact, a fairy-tale one. If infants represent objects as small and cuplike (either on their own or as a result of contextual manipulations), they expect them not to change spontaneously into objects that are large and pumpkinlike.

In the following sections of this article, I explain in more detail how infants' physical representations develop. I then return to the claims made in this section and review some of the evidence that supports them.

AN ACCOUNT OF INFANTS' PHYSICAL REASONING

Our account of infants' physical reasoning (Baillargeon et al., 2006, in press) assumes that when infants watch a physical event, their physical-reasoning system—an abstract computational system designed to monitor events as they unfold and to interpret and predict their outcomes—builds a specialized physical representation of the event. Any information included in this representation is interpreted in terms of infants' core concepts and principles.

In the first weeks of life, an infant's physical representation of an event typically includes only basic information about the event. This basic information encompasses both spatiotemporal and identity information. The spatiotemporal information specifies how many objects are involved in the event (up to some small number; e.g., Cheries, Wynn, & Scholl, 2006; Feigenson & Carey, 2005), and how their arrangement changes over time. The identity information provides categorical or ontological information about each object, such as whether it is inert or self-propelled (e.g., Luo, Kaufman, &Baillargeon, in press;Wu, Luo, &Baillargeon, 2006) and whether it is closed or open (e.g., is the object a closed object, container, cover, or tube? See Hespos & Baillargeon, 2001b; Wang, Baillargeon, & Paterson, 2005). Thus, while watching a red ball being alternately lowered behind and lifted above a screen, infants would represent the information "inert closed object being alternately lowered behind and lifted above inert closed object."

With experience, infants include more and more information in their physical representations of events as they identify the variables relevant for predicting outcomes. Variables are identified separately for each event category. In keeping with the basic information infants represent about events, early categories include *occlusion events* (object behind another object, or *occluder*), *containment events* (object inside container), *covering events* (object under cover), and *tube events* (object inside tube). Avariable calls infants' attention to a certain type of information in an event and provides a rule for interpreting this information. For example, the variable width in occlusion events calls infants' attention to the relative widths of objects and occluders and specifies that an object can be fully hidden behind an occluder if it is narrower, but not wider, than the occluder. Finally, variables are organized into vectors, and each new variable in a vector revises predictions from earlier variables. Figure 1 depicts the development of two vectors relevant to occlusion events: "When is an object behind an occluder hidden?" and "When is an object that reappears from behind an occluder the same object that disappeared behind it?"

As infants identify the variables relevant for predicting out-comes in each event category, their physical reasoning becomes increasingly sophisticated (see Fig. 2). When watching an event, infants begin by representing its basic information and then use this information to categorize the event. Infants then tap their knowledge of the selected category, which lists the variables identified for the category. Information about these variables is then included in the physical representation and is interpreted in accordance with the variable rules and core knowledge. Returning to our earlier example, while watching a red ball being alternately lowered behind and lifted above a screen, infants would first represent the basic information "inert closed object being alternately lowered behind and lifted above inert closed object." Infants would then categorize the event as an occlusion event, would access their knowledge of this event category, and would include information about all known relevant variables in their physical representation of the event. Thus, as suggested by the vectors in Figure 1, by 4 months of age, infants would include information about the shape of the ball, the relation between the lower edge of the screen and the supporting surface, and the relative heights and widths of the ball and screen; by 7.5 months, infants would include information about the pattern of the ball and the opacity of the screen; and by 11.5 months, infants would include information about the color of the ball.

CONTINUITY VIOLATIONS

Detecting Basic and Variable Continuity Violations

Our account predicts that infants should detect a continuity violation in an event only when their physical representation of the event includes the necessary information to detect the violation. Thus, a violation that involves only basic information—a *basic violation*—should be detected at an early age, because even very young infants would include this basic information in their physical representation of the event. In contrast, a violation that involves variable information—a *variable violation*—should be detected only after infants have identified the variable as relevant for predicting outcomes in the event's category and hence include information about the variable in their physical representation of the event.3

Consistent with the preceding analysis, there is now extensive evidence that (a) infants as young as 2.5 months of age succeed in detecting many different basic continuity violations, and (b) infants aged 2.5 months and older fail to detect many different variable continuity violations. To illustrate (see Fig. 3), at 2.5 months, infants detect a violation when an object disappears behind one occluder and reappears from behind another occluder without appearing in the gap between them (Aguiar & Baillargeon, 1999; Luo & Baillargeon, 2005). However (as suggested by Fig. 1a), prior to about 3 months, infants detect no violation if an object remains hidden when passing behind an occluder whose lower edge is not continuous with the surface on which it rests, thus creating an opening; prior to about 3.5 months, infants detect no violation if a tall object remains hidden when passing behind a short occluder; and at about 7 months, infants detect no violation when an object that is lowered behind a transparent occluder is not visible through the occluder (e.g., Aguiar & Baillargeon, 1999, 2002; Luo & Baillargeon, 2005, 2007).

Finally, because variables are identified separately for each event category, and the same variable is sometimes identified at different ages in different categories (age of identification depends primarily on age of exposure to appropriate observations; see Wang & Baillargeon, in press-a), infants may succeed in detecting a variable continuity violation in one event category but not in another, giving rise to striking lags or *décalages* in their responses to similar events from different categories. Thus, although infants are surprised at 3.5 months to see a tall object become fully hidden behind a short occluder, they are not surprised to see a tall object become fully hidden inside a short container until 7.5 months, under a short cover until 12 months, and inside a short tube until 14 months (see Fig. 4; Baillargeon & DeVos, 1991; Hespos & Baillargeon, 2001a; Wang et al., 2005).[4]

Inducing Infants to Detect Variable Continuity Violations

According to our account, infants who have not yet identified a variable as relevant to an event category typically do not include information about this variable when representing events from the category; as a result, they can detect no continuity violation involving the variable. This account predicts that if infants could be temporarily induced, through some contextual manipulation, to include information about a variable they have not yet identified, they should then be able to detect continuity violations involving the variable. The information, once represented, would become subject to the continuity principle, and events that unfold in a manner inconsistent with the principle would be flagged as violations.

Researchers have uncovered several different ways of temporarily inducing infants to include information about variables they have not yet identified when representing events

[3]The claim here is not that infants who fail to include information about a variable in their physical representation of an event fail to represent this information altogether—this information may well be represented in a separate, object-representation system (e.g., Li, Baillargeon, & Simons, 2006; Wang & Baillargeon, in press-b). Rather, the claim is that variable information is not routinely included in the physical-reasoning system until infants have learned that it can be used to predict outcomes.

[4]These décalages give rise to two issues. First, one might ask why infants identify the variable height earlier in, say, containment events than in covering or tube events. An initial assumption might be that infants view covers and tubes as more complex than containers, but this is incorrect: Infants as young as 2.5 months detect basic continuity violations in events involving containers or covers (e.g., Hespos & Baillargeon, 2001b; Wang et al., 2005). Rather, the variable height is identified sooner in containment events simply because infants are exposed at an earlier age to appropriate observations from which to abstract the variable. This analysis predicts that infants exposed to appropriate observations in the laboratory or home might identify height earlier as a covering or tube variable, and recent experiments support this prediction (e.g., Wang & Baillargeon, in press-a; Wang & Kohne, in press). Second, one might ask why infants, having identified height as a containment variable, do not then generalize this variable to other relevant categories, such as covering and tube events. We believe that the answer to this question has to do with the explanation-based learning process that underlies infants' identification of variables (e.g., DeJong, 1993; Wang & Baillargeon, in press-a). When exposed to appropriate observations for a variable, infants build an explanation for these observations using their core knowledge; the details of the explanation specify the range over which it can be generalized. Thus, in containment events, the explanation for the variable height very likely makes reference to the bottom surface of the container, and so the variable cannot be generalized to events involving covers or tubes, which have no bottom surface.

(e.g., Gertner, Baillargeon, & Fisher, 2005; J. Li & Baillargeon, 2007; Wang & Baillargeon, 2005). Infants' physical-reasoning system thus appears extremely porous—a highly desirable characteristic in a system that primarily learns to include more and more information over time.

For example, experiments involving a tracking manipulation take advantage of the fact that when infants see a sequence of two distinct events involving the same objects, and the object-tracking system can unambiguously track the objects from the first to the second event, the variable information included in the physical representation of the first event is carried over en bloc to that of the second event (such a strategy is, of course, highly efficient). This carry over of variable information can have a positive effect if infants first see an event in which a variable has been identified, followed by an event in which the variable has not yet been identified. Information about the variable is then carried over, fortuitously, to the physical representation of the second event. Once included, the variable information becomes subject to the continuity principle, allowing infants to detect violations.

To illustrate, one experiment (Wang & Baillargeon, 2005) built on prior findings that the variable height is identified at about 3.5 months in occlusion events, but not until about 12 months in covering events (see Fig. 4). Consistent with the preceding analysis, 8.5-month-olds detected a violation when a short cover was lowered over a tall object until it became fully hidden, if they first saw the cover being placed in front of (but not next to) the object. The infants included height information in their physical representation of the first event (occlusion) and then carried over this information to their physical representation of the second event (covering). This information then became subject to the continuity principle, allowing the infants to detect the violation in the event 3.5 months before they would normally have done so.

Experiments involving priming manipulations suggest that infants may be induced to detect a variable violation simply by exposure to a perceptual contrast designed to highlight the variable (e.g., exposure to multiple objects that are identical except that they present different values of the variable). For example, one experiment with 8-month-olds (J. Li & Baillargeon, 2007) focused on the variable height in tube events, which is typically not identified until about 14 months (see Fig. 4). The infants first received two static priming trials in which they saw three objects that differed only in height and were arranged monotonically. Next, the infants saw a test event in which an object (the tallest object in the priming trials) was removed from a much shorter tube. The infants detected the violation in the event, suggesting that the priming trials high-lighted height information and thus rendered the infants more likely to include such information in their physical representation of the test event. This information became subject to the continuity principle, allowing the infants to detect the violation in the event 6 months before they would have done so otherwise.

CHANGE VIOLATIONS

As mentioned earlier, initial investigations of infants' responses to change violations suggested that they typically failed to be surprised when objects underwent surreptitious changes in size, shape, pattern, or color (e.g., Newcombe et al., 1999; Simon et al., 1995). These results led to the view that infants have no expectation about objects' individual properties until they learn, for each object category, which spontaneous changes are possible and which are not (e.g., Scholl & Leslie, 1999; Xu & Carey, 1996). In this view, infants could not be surprised to see a cup change from small to large or from green to red until they learned that cups cannot undergo such changes spontaneously. Furthermore, infants who detected change violations in cups might not detect the same violations in shoes or balls if they had not yet learned which changes are possible in these other categories.

Recent findings (described later) have cast doubt on this view. First, rather than object-category effects, investigations of infants' responses to change violations have uncovered primarily event-category effects, just as with continuity violations. Whether infants detect a surreptitious change to the size, shape, pattern, or color of an object in an event seems to depend on the event rather than the object involved and, more specifically, on whether infants have identified the variable size, shape, pattern, or color as relevant for that event category. Second, as with continuity violations, infants can be temporarily induced to detect change violations through contextual manipulations. Once infants have included information about the size, shape, pattern, or color of an object in their physical representation of an event, they expect these properties not to change spontaneously in the course of the event.[5] Finally, as discussed later, the various findings presented here suggest that the distinction between continuity and change violations is somewhat illusory and that all of these violations may be understood more simply as persistence violations.

Detecting Basic and Variable Change Violations

According to our account of infants' physical reasoning, because the basic information in physical representations includes identity information and because this information, once represented, becomes subject to the persistence principle, even young infants should detect basic change violations when an inert object changes into a self-propelled object or when a closed object changes into an open one. Experiments are under way to test these predictions, and results thus far are promising.

Consistent with our account, infants fail to detect variable change violations in events from a category when they have not yet identified the relevant variables for the category. For example (as suggested by Fig. 1b), prior to about 7.5 months, infants detect no violation when an object with Pattern A disappears behind a narrow screen (large enough to hide only one object) and a similar object with Pattern B reappears from behind it. Likewise, prior to about 11.5 months, infants detect no violation when an object with Color A disappears behind a narrow screen and a similar object with Color B reappears from behind it (e.g., Wilcox, 1999).

Furthermore, because size, shape, pattern, and color are identified separately in each event category, décalages sometimes arise in infants' ability to detect similar variable change violations in different categories. Thus, at 4.5 months of age, infants are surprised when an object with Shape A disappears behind a narrow screen and an object with Shape B reappears from behind it, but they are not surprised when an object with Shape A is buried in one location in sand and an object with Shape B is retrieved from the same location (e.g., Newcombe at al., 1999; Wilcox, 1999).

Finally, and perhaps most strikingly, décalages have also been observed in infants' ability to detect the same change to the same object in different event categories. In a series of experiments, 8-month-olds were able to detect a surreptitious change to the height of an object when it was briefly lowered inside a container, but not inside a tube (J. Li & Baillargeon, 2007); 11-month-olds were able to detect a change to the height of an object when it was briefly hidden behind a cover, but not under a cover (Wang & Baillargeon, 2006); and 12.5-month-olds were able to detect a surreptitious change to the color of an

[5]This expectation applies somewhat differently to inert and self-propelled objects. By 5 months of age, infants seem to recognize that self-propelled objects can use their internal force (Leslie, 1994) to alter the orientation, though not the size, shape, pattern, and color, of their parts (Wu & Baillargeon, 2006, 2007).

object when it was briefly lowered behind an occluder, but not inside a container (Ng & Baillargeon, 2006).

Inducing Infants to Detect Variable Change Violations

Our account predicts that infants who fail to detect a variable change violation in an event should succeed in detecting this violation if temporarily induced, through contextual manipulations, to include information about the variable in their physical representation of the event. This information would then become subject to the principle of persistence, and the event should be flagged as a violation.

As was the case with variable continuity violations, there is now evidence that infants can be induced to detect variable change violations through tracking (J. Li&Baillargeon, 2005) as well as through priming manipulations. In seminal experiments, Wilcox and Chapa (2004) primed 7.5-month-olds to detect color change violations in occlusion events (recall that color is not identified as an occlusion variable until about 11.5 months; see Fig. 1b). After receiving priming trials in which green cups were used to pound pegs and red cups were used to pour salt, infants detected a violation when shown a test event in which a green ball and a red ball appeared successively from behind a narrow screen. This result suggested that the priming trials rendered the colors green and red salient by associating them with different functions (green pounds, red pours). As a result, infants were more likely to include information about the green and red balls in their physical representation of the test event. This color information became subject to the persistence principle, and the event was flagged as a violation: A green ball cannot spontaneously change into a red ball. Using a similar method, Wilcox and Chapa also successfully primed 4.5-month-olds to detect pattern change violations in occlusion events.

Simple exposure to a relevant perceptual contrast can also prime infants to detect a variable change violation (e.g., J. Li & Baillargeon, 2007; Ng & Baillargeon, 2006). For example, 12.5-month-olds were surprised when a purple doll was lowered inside a narrow container and an orange doll was then removed from it, if they first received a static priming trial showing four dolls that differed only in color (purple, orange, yellow, and pink). Infants were not surprised if shown only two dolls (purple and orange) in the priming trial, suggesting that at least three different colors were needed to create a salient perceptual contrast (Ng & Baillargeon, 2006).

Links Between Continuity and Change Violations

According to the account presented here, continuity and change violations are all, in essence, persistence violations.[6] If this analysis is correct, infants who detect continuity violations involving a particular variable in an event category should also detect change violations involving the same variable. Furthermore, manipulations that induce infants to include information about a variable they have not yet identified should make it possible for them to detect either continuity or change violations involving the variable. Both of these predictions have been confirmed. For example, previous research has found that 8-month-olds are surprised when a tall object either becomes fully hidden inside a short container or

[6]In our account, cohesion violations are also persistence violations; whether they are basic or variable violations depends on how the violations are accomplished. If an object breaks apart in plain view, basic spatiotemporal information would allow infants to detect the change from one to two objects, and the persistence principle would flag the event as a violation. If a screen is lifted to hide an object, and only half of the object emerges from behind the screen, variable information (e.g., about the size or shape of the original object) would be necessary for infants to detect the violation. Consistent with this analysis, basic cohesion violations are detected very early: If 3-month-old infants construe (rightly or wrongly) a collection of adjacent surfaces as a single object, they are surprised if it breaks apart in plain view (e.g., Needham, 1999, 2000; Spelke et al., 1993). Variable cohesion violations have not been examined to date, though experiments are under way.

is much shorter after being briefly lowered inside a tall container (e.g., Hespos & Baillargeon, 2001a; J. Li & Baillargeon, 2007). Moreover, after receiving priming trials in which they see three objects that differ only in height, 8-month-olds are surprised if the tallest object is then removed from a much shorter tube or is much shorter after being briefly lowered inside a tall tube (J. Li&Baillargeon, 2007).

So far, I have used the term *change violations* to refer to events in which the same object is seen to have different individual properties at different times (and this change appears to be spontaneous or uncaused), and I have used the term *continuity violations* to refer to events in which the respective properties of the objects involved make their interaction impossible: For the event to unfold as it does, one or more objects must spontaneously appear or disappear or must occupy space already occupied by other objects. However, the difference between change and continuity violations is not as sharp as this distinction implies. When a tall object becomes fully hidden inside a short tube standing on a table, one can, in principle, describe the event either as a change violation (i.e., the object fails to maintain its height out of sight inside the tube) or as a continuity violation (i.e., the object appears to go through the table). Recognizing that change and continuity violations are all persistence violations does, of course, resolve these ambiguities.

This discussion becomes especially relevant when dealing with violations that can be construed as either change or continuity violations (Wu et al., 2006). In a recent experiment, 4-month-olds received a familiarization trial in which an experimenter’s hand lifted a red column and a black ball in alternation above the center of a wide screen between two small, closed windows (see Fig. 5). Each window could be opened by lifting a handle that protruded above the screen. In the expected test event, the hand opened the right window to reveal the column and then opened the left window to reveal the ball. In the unexpected test event, the hand opened the right window to reveal the column and then again opened the right window to reveal the ball. The infants looked reliably longer at the unexpected than at the expected event, suggesting that they realized that the column and ball were two different objects that had to occupy different locations behind the screen. Control results confirmed that the infants detected the violation in the unexpected event. Critically, this violation could be described either as a change violation (i.e., the two objects appeared to change into each other) or as a continuity violation (i.e., the two objects appeared to occupy the same location behind the screen).

INDIVIDUATION VIOLATIONS

Infants who include size, shape, pattern, or color information in their physical representations should detect not only change violations when objects appear to change spontaneously, but also individuation violations when the number of objects revealed is inconsistent with the variable information provided. An event in which a small, green ball disappears behind a large screen and a small, red ball then appears from behind it is not a change violation because the screen is wide enough to hide both balls at once (and indeed, infants do not see such events as change violations; e.g., Ng & Baillargeon, 2006; Wilcox, 1999). However, if the screen is then removed to reveal only one ball, infants should detect an individuation violation: The variable information indicated that at least two balls were present behind the screen, and yet only one ball was revealed.

Xu and Carey (1996) were the first to show that infants younger than 1 year of age who detect change violations involving a variable may nevertheless fail to detect individuation violations involving the same variable. Two factors seem to contribute to infants’ difficulty with individuation violations. First, infants are presented with a sequence of two distinct events (e.g., an event with and then without an occluder) and cannot use their object-tracking system to unambiguously track the objects from the first to the second event. To determine how many objects should be present in the second event, infants must therefore recall the first event and establish how many objects were present. Second, this task becomes especially difficult when the first event involved multiple emergences of the objects on either side of the screen. Because infants cannot then recall the entire event, they rely on alternative strategies for mapping the object information from the first to the second event, and these strategies often yield incorrect solutions (X. Li, Baillargeon, House, Carey, & Bonatti, 2007).

The preceding analysis suggests that infants should succeed in detecting individuation violations as long as mapping difficulties are absent or reduced, and there is now extensive evidence supporting this suggestion (Wilcox, Schweinle, & Chapa, 2003). For example, infants aged 5.5 months and older succeed when the occlusion event is very brief: Object A disappears behind the left edge of the screen, Object B appears at the right edge, and then the screen is removed to reveal no Object A behind it (Wilcox & Baillargeon, 1998; Wilcox & Schweinle, 2002). Furthermore, infants aged 8.5 months and older succeed even with a longer occlusion event if the screen is lowered to reveal a second, transparent screen: Infants represent an on-going occlusion event involving first an opaque and then a transparent occluder, and they use whatever variable information is included in their physical representation of the event to detect individuation violations (e.g., Ng, Baillargeon, &Wilcox, 2007; Wilcox & Chapa, 2002).

To illustrate, in a recent experiment (Ng et al., 2007), 8.5-month-olds (who have identified size, shape, and pattern but not color as occlusion variables; see Fig. 1b) saw an experimenter’s hand move a green cylinder with yellow dots behind a large screen (see Fig. 6). Next, the hand brought out a similar green cylinder with either yellow stripes (pattern event) or red dots (color event) and then returned it behind the screen. Finally, the hand brought out the yellow-dotted cylinder again, and the screen was then lowered to reveal a second, transparent screen; no cylinder stood behind this screen. As predicted, the infants detected the individuation violation in the pattern but not the color event: They included no color information in their physical representations of the events, and hence assumed that a single cylinder was present in the color event.

CONCLUDING REMARKS

As was explained in the introductory section of this article, the notion of innate ideas has a very long history in the fields of philosophy and cognitive science. This history continues: I have argued that one of the innate ideas that guide infants’ physical reasoning is a principle of persistence, which states that objects persist, as they are, in time and space. Infants fail to detect persistence violations when they fail to include the necessary information in their physical representations of events or when they have difficulty mapping this information from one physical representation to another. Both of these limitations disappear gradually with development.

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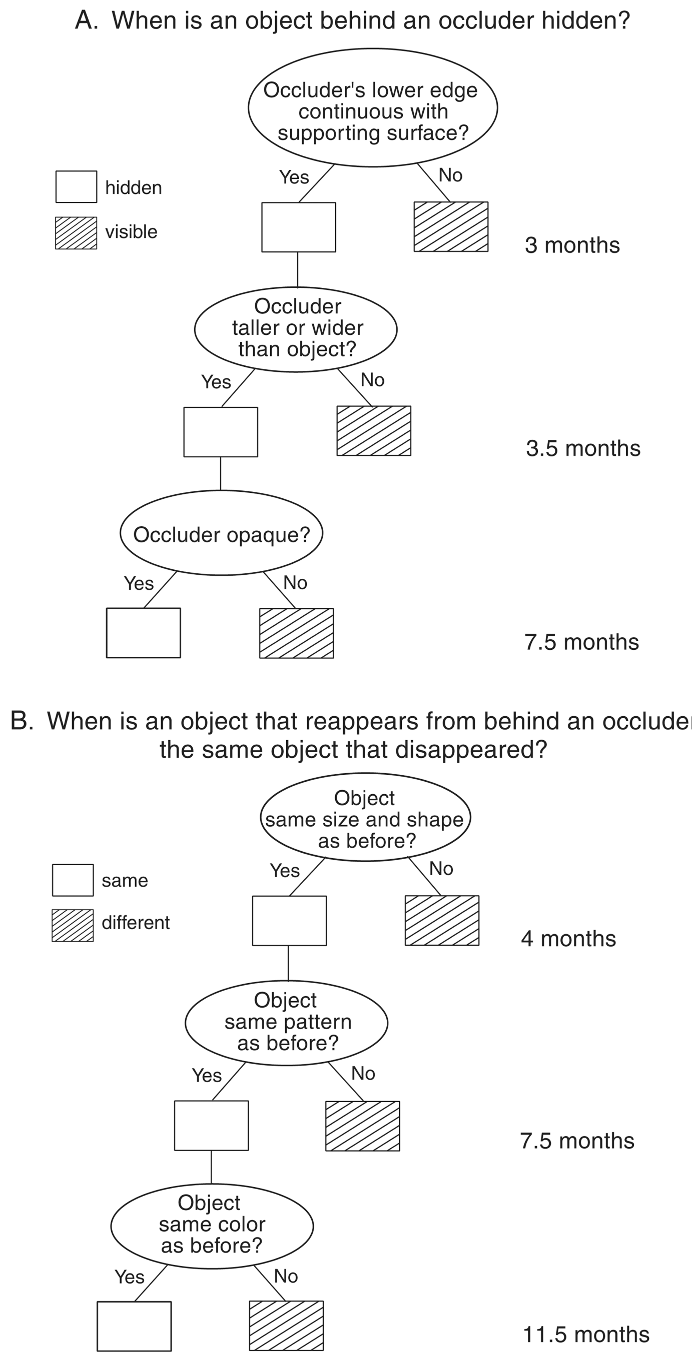

Fig. 1.

Decision trees representing two vectors relevant to occlusion events. A: Vector representing some of the variables infants identify as they learn when an object behind an occluder is hidden or visible. B: Vector representing some of the variables infants identify as they learn when an object that reappears from behind an occluder is the same object that disappeared or a different object. The ages in each vector represent the approximate ages at which the variables are identified.

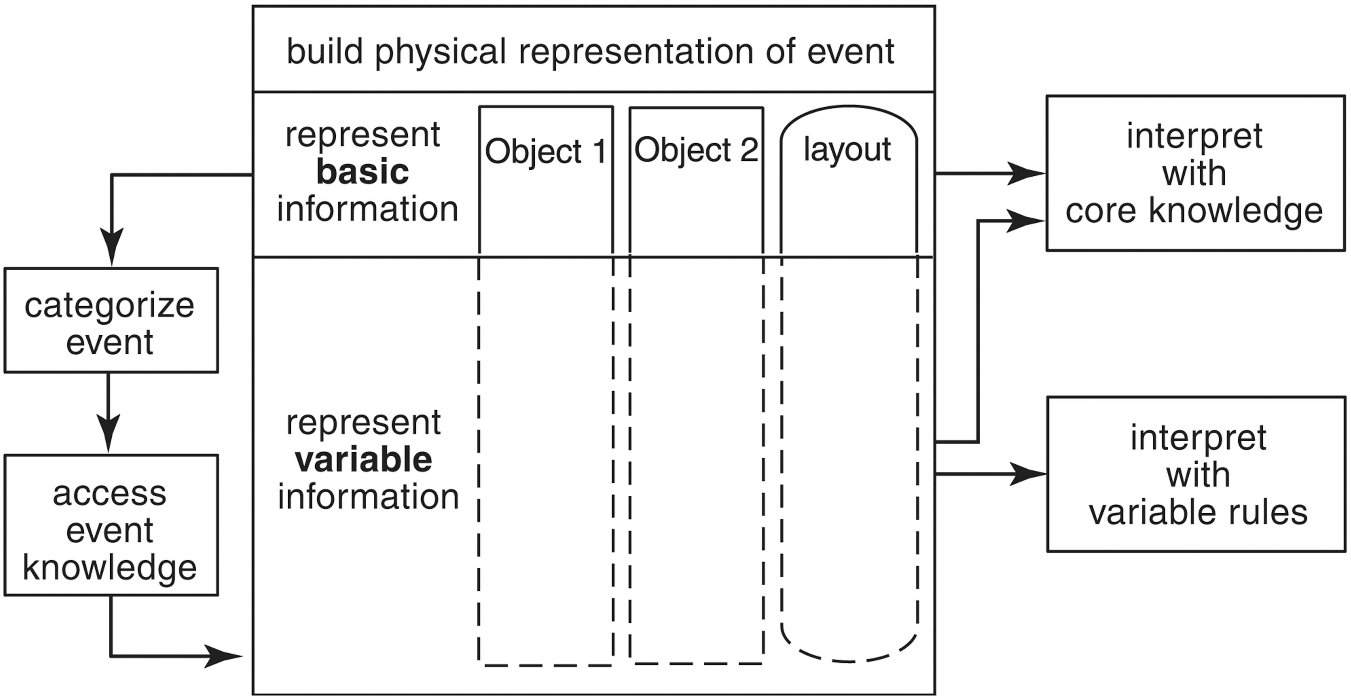

Fig. 2.
Schematic diagram of infants' physical reasoning showing how infants represent and interpret the basic and variable information about a physical event. This hypothetical event involves two objects (Object 1 and Object 2). The layout component represents their spatial arrangement over time as the event unfolds.

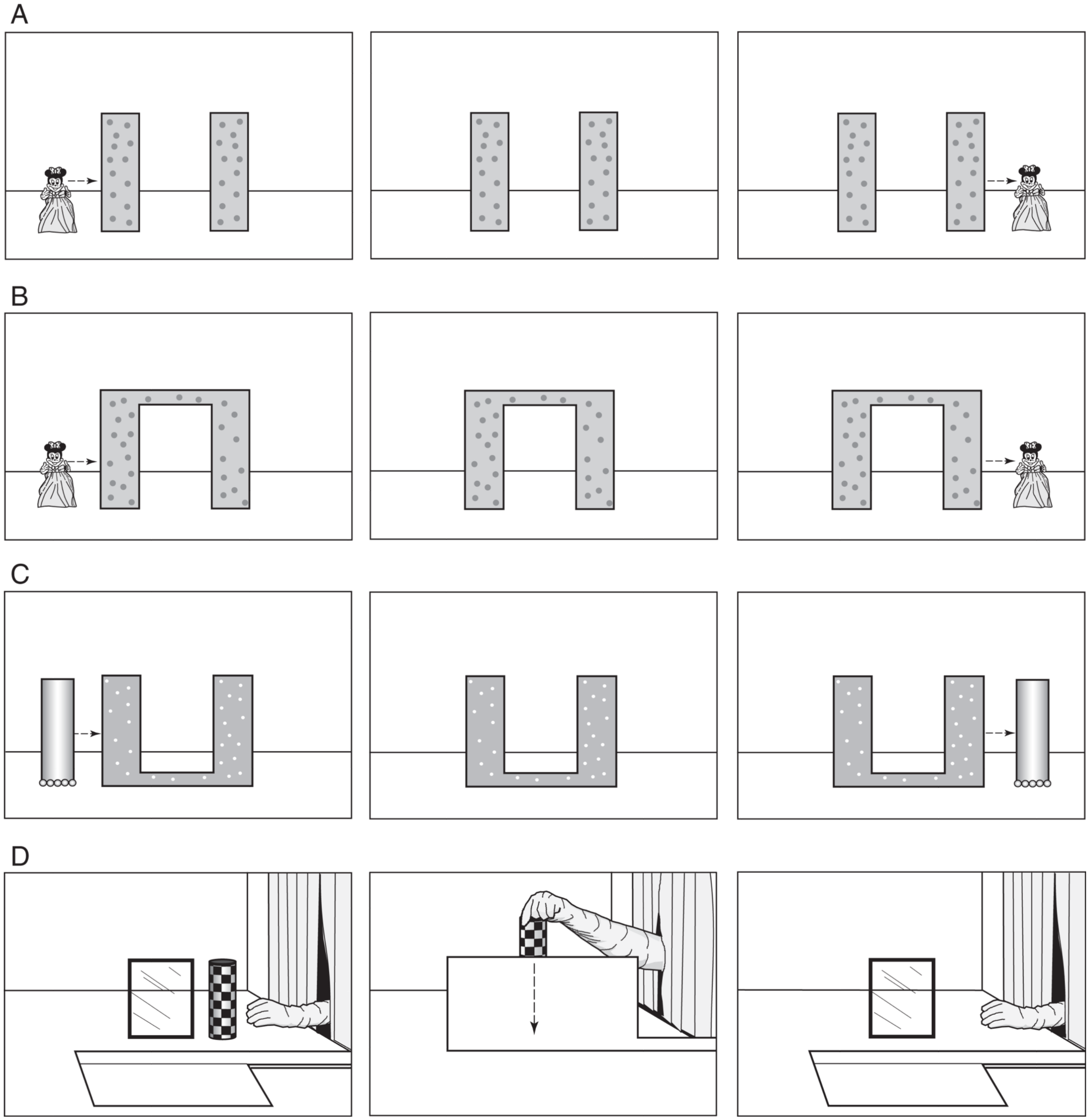

Fig. 3.

Examples of continuity violations involving occlusion events. A: At 2.5 months, infants are surprised if an object fails to become visible when passing between two screens placed a short distance apart (Aguiar & Baillargeon, 1999). B: Beginning at about 3 months, infants are surprised if an object fails to become visible when passing behind a screen whose lower edge is not continuous with the surface on which it rests, thus creating an opening between the screen and the surface (Aguiar & Baillargeon, 2002). C: Beginning at about 3.5 months, infants are surprised if a tall object fails to become visible when passing behind a short screen (Luo & Baillargeon, 2005). D: Beginning at about 7.5 months, infants are surprised when shown the following violation. Infants first see an object and a transparent occluder standing side-by-side. A large screen is raised to hide the display, and an experimenter's gloved hand places the object behind the transparent occluder. The screen is then lowered to reveal the transparent occluder with no object visible behind it (Luo & Baillargeon, 2007).

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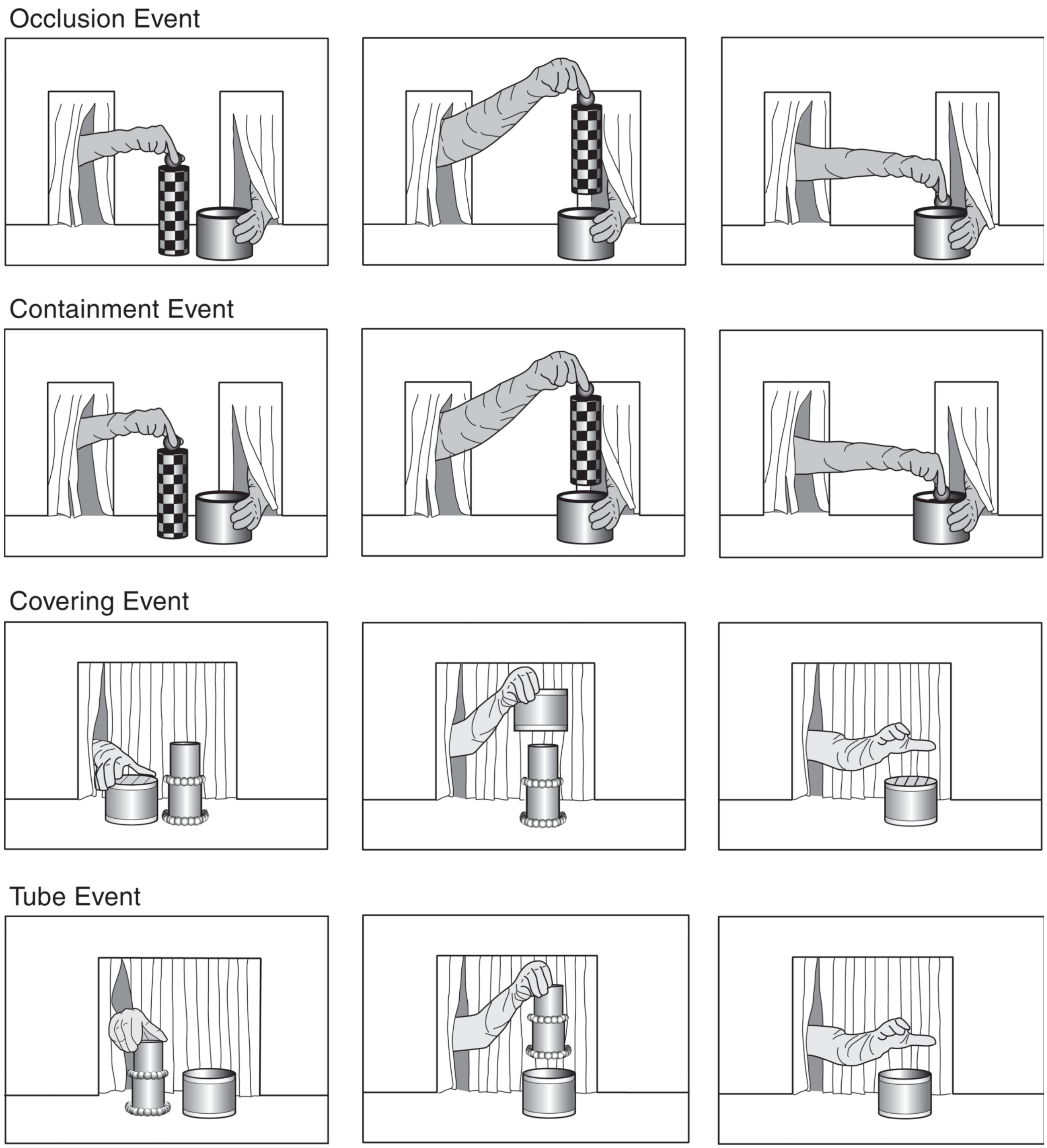

Fig. 4.
Examples of décalages in infants' reasoning about the variable height in different event categories. Infants are surprised to see a tall object become almost fully hidden behind a short container (occlusion event) at 4.5 months, but they are not surprised to see a tall object become almost fully hidden inside a short container (containment event) until about 7.5 months (Hespos & Baillargeon, 2001). Infants are surprised to see a tall object become fully hidden under a short cover (covering event) at 12 months, but they are not surprised to see a tall object become fully hidden inside a short tube (tube event) until 14 months (Wang et al., 2005).

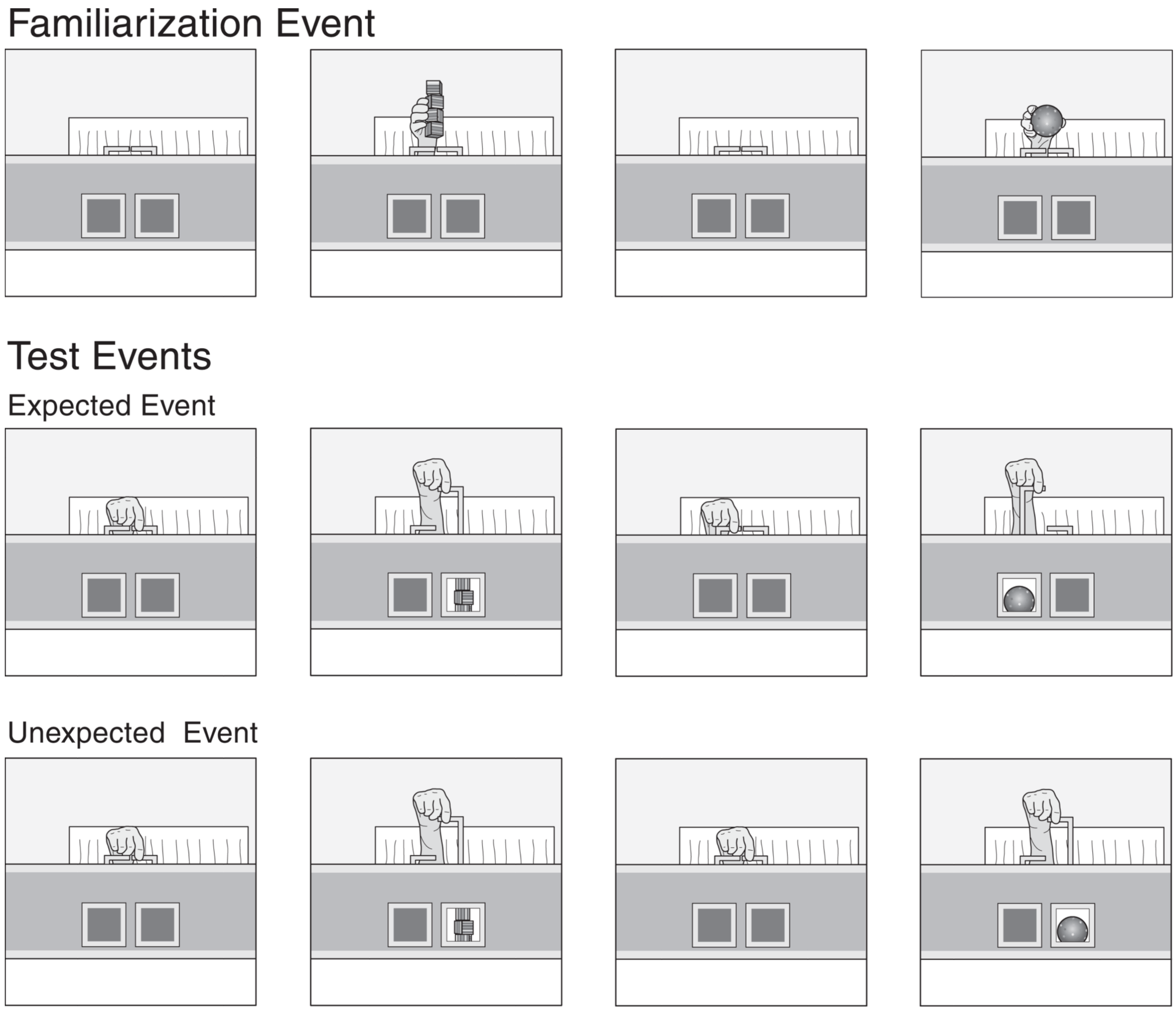

Fig. 5.

Familiarization and test events shown in Wu et al. (2006). In the familiarization event, an experimenter's gloved hand lifted a red column and a black ball in alternation above the center of a wide screen, between two small, closed windows. Each window could be opened by lifting a handle that protruded above the screen. In the expected test event, the hand opened the right window to reveal the column and then opened the left window to reveal the ball; this sequence was repeated until the trial ended. In the unexpected test event, the hand opened the right window to reveal the column and then again opened the right window to reveal the ball; this sequence was repeated until the trial ended.

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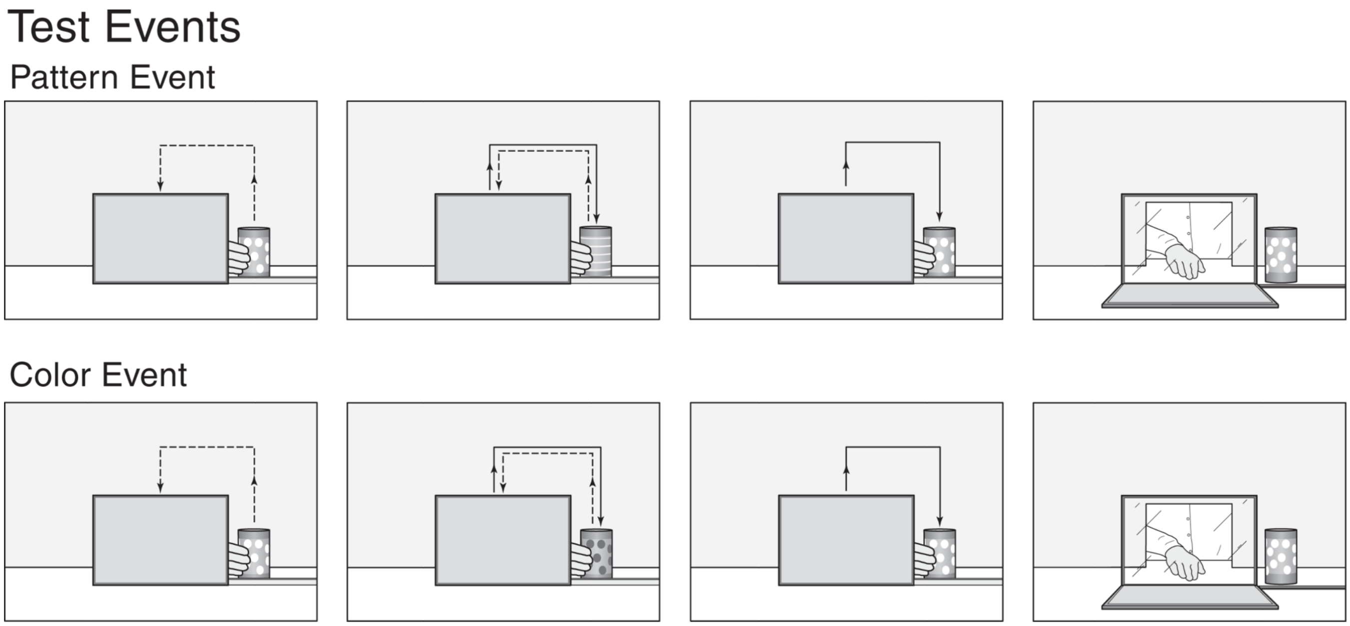

Fig. 6.

Test events shown in Ng et al. (2007). At the start of each event, a green cylinder with yellow dots stood on an apparatus floor to the right of a large opaque screen. An experimenter's hand lifted the cylinder, moved it to the left, and then lowered it behind the center of the screen; at that point, the experimenter's hand was no longer visible. After a pause, the hand brought out a similar green cylinder with either yellow stripes (pattern event) or red dots (color event) and then returned it behind the screen. Next, the hand brought out the yellow-dotted cylinder again. Finally, the screen was lowered to reveal a second, transparent screen; no cylinder stood behind this screen.