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Infants' Physical Knowledge: Of Acquired Expectations and Core Principles

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Over the past ten years, there have been at least two distinct trends in the research on infants' understanding of the physical world. Spelke and her colleagues (e.g., see Spelke, 1994; Spelke et al., 1992; Spelke, Phillips, and Woodward, 1995) have sought to ascertain whether core principles constrain, from a very early age, infants' interpretations of physical events. Two of the core principles proposed by Spelke are those of *continuity* (objects exist and move continuously in time and space) and *solidity* (two objects cannot exist at the same time in the same space).

Other investigators, myself included (e.g., see Aguiar and Baillargeon, 1999; Baillargeon, 1991; Hespos and Baillargeon, 2001b; Kotovsky and Baillargeon, 1998; Needham and Baillargeon, 1993; Sitskoorn and Smitsman, 1995; Wilcox, 1999), have attempted to uncover how infants' physical knowledge develops—what expectations are acquired at what ages, and what learning processes make possible these acquisitions.

Although until recently these two lines of investigation have coexisted largely independently, these carefree days are now over. The more we find out about how infants acquire their physical knowledge, the more absorbed we become by questions concerning the potential role of core principles in infants' interpretations of physical events.

This chapter is organized into two main sections. In the first, I review recent findings from my laboratory and elsewhere on infants' acquisition of physical knowledge. In the second section, I consider the implications of some of these findings for Spelke's (e.g., see Spelke, 1994; Spelke et al., 1992, 1995) claim that, from a very early age, continuity and solidity principles guide infants' reasoning about physical events. In particular, I point out that these findings indicate that infants *fail* to detect many salient continuity and solidity violations. I then propose a way in which these failures might be reconciled with Spelke's claim, and suggest a possible experimental test of this approach.

It seemed fitting to offer these speculations in the present context because Jacques Mehler, as we all know, has always been extremely supportive of new ideas in infant cognition. Unlike most journal editors, who seem inclined to tie their authors' hands and feet, Jacques Mehler, as editor of *Cognition,* has always allowed his authors sufficient rope to leap to new and provocative conclusions (or, of course, to hang themselves, depending on one's point of view). I am very grateful to Jacques for his openness and support over the years, and humbly dedicate the following pages to him.

How Do Infants Learn about the Physical World?

Infants' Identification of Initial Concepts and Variables

For many years, my collaborators and I have been exploring infants' acquisition of physical knowledge (for reviews, see Baillargeon, 1995, 1998, and Baillargeon, Kotovsky, and Needham, 1995). We have found that, when learning about support, occlusion, collision, and other physical events, infants first form an *initial concept* centered on a primitive, all-or-none distinction. With further experience, infants identify a sequence of discrete and continuous *variables* that refine and elaborate this initial concept, resulting in increasingly accurate predictions and interpretations over time. To illustrate this general pattern, I briefly describe the results of experiments on infants' expectations about support and occlusion events.

Support Events In our experiments on the development of infants' knowledge about support events (e.g., see Baillargeon, Needham, and DeVos, 1992; Needham and Baillargeon, 1993; for reviews, see Baillargeon, 1995, 1998, and Baillargeon et al., 1995), infants aged 3 to 12½ months were presented with support problems involving a box and a platform; the box was held in one of several positions relative to the platform, and the infants judged whether the box should remain stable when released. The results indicated that, by 3 months of age, infants have formed an initial concept of support centered on a simple *contact/*

no-contact distinction: they expect the box to remain stable if released in contact with the platform and to fall otherwise. At this stage, any contact with the platform is deemed sufficient to ensure the box's stability. In the months that follow, infants identify a sequence of variables that progressively revise and elaborate their initial concept. At about 4½ to 5½ months of age, infants begin to take into account the *type of contact* between the box and the platform. Infants now expect the box to remain stable when released on but not against the platform. At about 6½ months of age, infants begin to consider the *amount of contact* between the box and the platform. Infants now expect the box to remain stable only if over half of its bottom surface rests on the platform.[1] At about 8 months of age, infants begin to distinguish between situations in which the *side or middle portion* of the box's bottom surface rests on a platform; they recognize that, in the latter case, the box can be stable even if less than half of its bottom surface is supported.[2] Finally, at about 12½ months of age, infants begin to attend to the *proportional distribution* of the box; they realize that an asymmetrical box can be stable only if the proportion of the box that rests on the platform is greater than that off the platform.

Occlusion Events In our experiments on the development of young infants' expectations about occlusion events (e.g., see Aguiar and Baillargeon, 1999, in press; Baillargeon and DeVos, 1991; Luo, 2000; for reviews, see Baillargeon, 1998, 1999), infants aged 2½ to 3½ months watched a toy move back and forth behind a large screen; next, a portion of the screen was removed, and the infants judged whether the toy should remain hidden or become (at least partly) visible when passing behind the screen. The results indicated that, by 2½ months of age, infants have formed an initial concept of occlusion centered on a simple *behind/not-behind* distinction. When the entire midsection of the screen is removed to form two separate screens, infants expect the toy to become visible in the gap between them. However, if the screens remain connected at the top or at the bottom by a narrow strip, infants no longer expect the toy to become visible: they view the connected screens as a single screen, and they expect the toy to be hidden when behind it. Over the course of the next month, infants rapidly progress beyond their initial concept. At about 3 months of age, infants begin to consider the presence of a *discontinuity in the lower edge* of the screen. Although infants still expect the toy to remain hidden when passing behind two screens that are connected at the bottom by a narrow strip, they now expect the toy to become visible when passing behind two screens that are connected at the top by a narrow strip. Finally, at about 3½ months of age, infants begin to consider the relative *heights* of the toy and screen. When the toy passes behind two screens that are connected at the bottom by a narrow or wide strip, infants expect the toy to become partly visible if it is taller but not shorter than the strip.

Infants' Formation of Event Categories

How general or specific are the expectations that infants acquire about physical events? Do infants acquire *general* expectations that are applied broadly to all relevant events, or *specific* expectations that remain tied to the events where they are first acquired? Our initial investigations of infants' physical knowledge could not provide an answer to this question, because they focused on events such as support and occlusion events that implicated very different expectations. In recent experiments, my collaborators and I have begun comparing infants' acquisition of similar expectations across events (e.g., see Hespos, 1998; Hespos and Baillargeon, 2001a; Wang and Paterson, 2000). The experiments test whether an expectation revealed in the context of one event (e.g., height in occlusion events) is typically also revealed in the context of other relevant events (e.g., height in containment events).

The results we have obtained to date do not support the notion that infants acquire general expectations that are applied broadly to all relevant events. Rather, our results suggest that infants' expectations are *event-specific:* infants appear to "sort" physical events into narrow event categories, and to learn separately how each category operates. A variable acquired in the context of one event category is not generalized to other relevant categories; it is kept tied to the specific category where it is first identified. As a result, infants must sometimes "relearn" in one event category a variable they have already acquired in another category. When weeks or months separate the acquisition of the variable in the two categories, striking lags (or, to borrow a Piagetian term, décalages) can be observed in infants' responses to events from the two categories. To illustrate this pattern, I briefly describe the results of recent experiments on infants' responses to height and transparency information in occlusion, containment, and other events.

Height Information In a first series of experiments (Hespos and Baillargeon, 2001a), 4½- to 7½-month-old infants saw an object being lowered behind an occluder or inside a container; the heights of the object and occluder or container were varied, and the infants judged whether the object could be fully or only partly hidden. The occlusion and containment events were made as perceptually similar as possible (e.g., in some of the experiments, the occluders were identical to the containers with their backs and bottoms removed; at the start of the experiment, the occluders and containers were rotated forward so that the infants could inspect them). The results indicated that, at 4½ months of age, infants are surprised to see a tall object become fully hidden behind a short occluder. In marked contrast, 4½-, 5½, and 6½-month-old infants are *not* surprised to see a tall object become fully hidden inside a short container; only 7½-month-old infants reliably detect this violation. These results, together with those discussed in the last section, suggest that although infants realize at about 3½ months of age that the height of an object relative to that of an occluder determines whether the object can be fully or only partly hidden when behind the occluder (Baillargeon and DeVos, 1991), it is not until four months later, at about 7½ months of age, that infants realize that the height of an object relative to that of a container determines whether the object can be fully or only partly hidden when inside the container.[3]

In a second series of experiments (Wang and Paterson, 2000), 9-month-old infants saw an object either being lowered inside a container, being lowered inside a tube, or being covered with a rigid cover; the height of the container, tube, or cover was varied, and the infants judged whether the object could be fully or only partly hidden. As before, efforts were made to render the events as perceptually similar as possible (e.g., the tubes were identical to the containers with their bottoms removed, and the covers were identical to the containers turned upside down; prior to the experiment, the infants were allowed to inspect the containers, tubes, or covers). As expected, given the results of the previous experiments, the data showed that 9-month-old infants are surprised to see a tall object become fully hidden inside a short container. However, infants this age are not surprised to see a tall object become fully hidden inside a short tube or under a short cover. We are currently testing older infants to find out at what age infants begin to realize that the height of an object relative to that of a tube or cover determines whether the object can be fully or only partly hidden when inside the tube or under the cover.

Together, the results of these experiments suggest that infants view events involving occluders, containers, tubes, and covers as belonging to separate categories, and do not generalize information acquired in one category to the others. Infants begin to consider height information in occlusion events at about 3½ months of age, in containment events at about 7½ months of age, and in events involving tubes and covers at some point beyond 9 months of age.

Transparency Information In an ongoing series of experiments (Luo and Baillargeon, in preparation), 8½- and 10-month-old infants see an object being lowered behind a transparent occluder or inside a transparent container (the occluder and container are made of Plexiglas and their edges are outlined with red tape; the infants are allowed to inspect the occluder or container prior to being tested). The experiments examine whether the infants realize that the object should be visible through the occluder when placed behind it, or through the front of the container when placed inside it. The occluder and container events are highly similar perceptually (e.g., the occluder is identical to the front of the container). Our results to date indicate that, at 8½ months of age, infants expect an object to be visible when lowered behind a transparent occluder, but not when lowered inside a transparent container. It is not until infants are about 10 months of age that they are surprised when an object is lowered inside a transparent container which is then revealed to be empty. We are now conducting experiments with younger infants to find out at what age infants first succeed at reasoning about transparency information in occlusion events.

These transparency experiments provide further evidence that infants view containment and occlusion events as belonging to distinct categories, and learn separately about each category. Infants identify the variable transparency first in the context of occlusion events, and only after some time in the context of containment events.

Additional Remarks On reflection, it is not very surprising that infants should use a learning strategy of forming narrow event categories and identifying variables separately for each category. Overall, this strategy must greatly facilitate infants' acquisition of physical knowledge; after all, breaking down the task of learning into smaller, more manageable components is a time-honored solution to the difficulties of knowledge acquisition.

Future research will need to address many questions about the nature and formation of infants' event categories. For example, on what basis are these categories generated? Why are occlusion and containment, in particular, regarded as distinct categories? In many cases (and contrary to those examined in this section), occlusion and containment outcomes differ: for example, an object that has been lowered inside a container typically moves with it when displaced, whereas an object that has been lowered behind an occluder does not. Could such causal regularities (which even 2½-month-old infants can detect; Hespos and Baillargeon, 2001b) provide the basis for infants' event categories (e.g., see Keil, 1995; Leslie, 1994; Pauen, 1999)?

What of other distinctions infants appear to draw, such as that between events including containers and tubes? Do infants recognize that in some cases tube outcomes differ from containment outcomes (e.g., an object that has been lowered inside a tube typically moves with it when slid to the side but not when lifted)? Or do infants possess a notion of a prototypical container, and do not categorize as containment events involving tubes or other nonprototypical containers (e.g., a box with a back much taller than its other three sides)?

Finally, at what point in development do infants begin to weave together their knowledge of different event categories? And what role do language and other cognitive processes play in this unification or redescription process (e.g., see Karmiloff-Smith, 1992)?

How Do Infants Identify Variables?

The results presented in the previous sections suggest that infants form narrow event categories and identify variables separately for each category. How do infants go about identifying these variables? My colleagues and I (e.g., see Aguiar and Baillargeon, 1999; Baillargeon, 1999; Hespos and Baillargeon, 2001b) have proposed that what typically triggers the identification of a variable in an event category is exposure to contrastive outcomes that cannot be explained or predicted by infants' current knowledge of the category. When infants register these contrastive outcomes, they seek out the conditions that map onto the outcomes.[4] Identification of these condition-outcome relations signals the identification of a new variable.[5]

This brief description leaves many questions unanswered about the process responsible for infants' identification of variables. Clearly, a great deal of research will be needed to fully specify the nature of this process. Nevertheless, it is possible to offer educated guesses about some of the factors likely to affect the ages at which specific variables are identified. Two such factors are briefly discussed below.

Exposure to Relevant Outcomes One factor likely to affect the age at which infants identify a variable is age of exposure to contrastive outcomes for the variable. Obviously, if infants are not exposed to contrastive outcomes for a variable, they will not begin the process of seeking out the conditions responsible for the outcomes. To illustrate, consider the finding, discussed earlier, that infants do not identify amount of contact as a support variable until about 6½ months of age (e.g., see Baillargeon et al., 1992). We have suggested that infants do not acquire this variable sooner in part because they are not exposed to appropriate contrastive outcomes sooner. In their daily lives, infants often see their caretakers place objects on supports (e.g., plates on tables or bottles on counters). However, in most instances, the objects remain stable when released; only in rare accidental cases do the objects fall. Hence, it is typically not until infants themselves begin to deposit objects on supports (presumably after 6 months of age, when they begin to sit independently; e.g., see Rochat, 1992) that they finally have the opportunity to notice that objects placed on supports sometimes remain stable and sometimes do not. At that point, infants begin to seek out the conditions that are responsible for these different outcomes, and eventually come to the conclusion that an object on a support can be stable when a large but not a small portion of its bottom surface rests on the support.[6]

Availability of Data on Relevant Conditions Another factor likely to affect the age at which infants identify a variable is how easy it is for them, after they are exposed to the relevant contrastive outcomes, to uncover the conditions that map onto the outcomes. To illustrate, consider the finding, discussed in the preceding section, that infants do not identify height as a containment variable until about 7½ months of age (Hespos, 1998; Hespos and Baillargeon, 2001a). In order to identify this variable, infants must be able to encode information about the heights of objects and containers. Prior research (e.g., see Baillargeon, 1991, 1994, 1995) suggests that, when infants begin to reason about a continuous variable in an event category, they can do so qualitatively, but not quantitatively: they cannot encode and remember information about absolute amounts.[7] To encode information about the heights of objects and containers qualitatively, infants must compare them as they stand side by side. Unfortunately, infants may witness relatively few instances in which objects are placed first next to and then inside containers; caretakers will more often insert objects directly into containers, allowing infants no opportunity to compare their heights. In the scenario outlined here, infants would thus notice that objects lowered inside containers are sometimes fully and sometimes only partly hidden. However, infants would have difficulty collecting data about the relative heights of the objects and containers, because they would have limited opportunities (perhaps until they themselves begin placing objects in containers) to see the objects standing next to the containers.

Additional Remarks The preceding speculations suggest possible explanations for the lags described earlier in infants' identification of similar variables across event categories. Consider, for example, the findings that infants identify height as an occlusion variable at about 3½ months of age (Baillargeon and DeVos, 1991), and as a containment variable at about 7½ months of age (Hespos, 1998; Hespos and Baillargeon, 2001a). It may be, of course, that in their daily lives infants observe many more occlusion than containment events, and hence can learn about occlusion events earlier. However, another possibility, related to the second factor discussed above, is that infants can more easily collect qualitative data about the relative heights of objects and occluders than of objects and containers. In the case of occlusion, infants will not only see objects being lowered from above behind occluders—they will also see objects being pushed from the side behind occluders (e.g., as when a parent slides a cup behind a box, or a sibling steps behind an armchair). In these side occlusions, it will usually be possible for infants to qualitatively compare the heights of the objects and their occluders; infants will then be in a position to begin mapping conditions onto outcomes.

The importance placed here on the availability of qualitative observations for the identification of continuous variables makes a number of interesting developmental predictions. For example, this approach suggests that, in containment events, infants should learn the variable width before height, because each time an object is lowered inside a container infants can compare their relative widths. And indeed, findings by Sitskoorn and Smitsman (1995) and Aguiar and Baillargeon (2000) indicate that infants do identify width before height as a containment variable, at some (still undefined) point between 4 and 6 months of age. Another prediction is that, in occlusion events, the variables height and width should be identified at about the same time, assuming that infants are exposed to occlusions from above and from the side about equally often. Preliminary results (Baillargeon and Brueckner, 2000) support this prediction.

What about the additional findings that infants do not consider height information in events involving tubes or covers until some point beyond 9 months of age (Wang and Paterson, 2000; see also Baillargeon, 1995, for similar results with events involving nonrigid covers)? One possibility is that young infants are not exposed to events involving tubes and covers often enough, and with sufficient opportunity for qualitative height comparisons, to be able to identify height as a relevant variable.

One way to test the general approach presented here would be to conduct observational studies to assess how often infants are presented with various occlusion, containment, and other events. The rationale of the studies would be to determine whether age of identification of variables can indeed be predicted from age of exposure to relevant condition-outcome data. A second way to test our general approach (and one we are actively pursuing) is to attempt to "teach" infants variables they have not yet acquired. Our view suggests that infants should acquire variables sooner than they would otherwise if exposed in the laboratory to appropriate condition-outcome observations. For example, infants should be able to identify the variable height in containment events prior to 7½ months of age if shown objects being placed next to and then inside containers of varying heights. Although we have not yet attempted to "teach" infants about height in containment, other experiments designed to teach 11-month-old infants the variable proportional distribution (described earlier) in support events have been highly successful (e.g., see Baillargeon, Fisher, and DeJong, 2000; for reviews, see Baillargeon, 1998, 1999). In addition, ongoing experiments in which Su-hua Wang and I are attempting to teach 9-month-old infants the variable height in covering events appear promising.[8]

Infants' Failures to Detect Continuity and Solidity Violations

If infants' interpretation of physical events is constrained from a very early age by continuity and solidity principles, as Spelke (e.g., see Spelke, 1994; Spelke et al., 1992, 1995) has suggested, we might expect infants to consistently detect all salient violations of these principles. However, this is not the case: infants often fail to detect even marked continuity and solidity violations. To illustrate, consider once again six of the results presented earlier: (1) 2½-month-olds are surprised when an object disappears behind one screen and reappears from behind another screen—but not when the two screens are connected at the top by a narrow strip (Aguiar and Baillargeon, 1999; Luo, 2000); (2) unlike 2½-month-olds, 3-month-olds are surprised when an object fails to appear between two screens that are connected at the top by a narrow strip; however, they are not surprised when the object fails to appear between two screens that are connected at the bottom by a narrow strip (Aguiar and Baillargeon, in press; Baillargeon and DeVos, 1991; Luo, 2000);

(3) 4-month-olds are not surprised when a wide object is lowered inside a container with a narrow opening (Sitskoorn and Smitsman, 1995); (4) 4½- to 6½-month-olds are not surprised when a tall object is fully hidden inside a short container (Hespos, 1998; Hespos and Baillargeon, 2001a); (5) 8½-month-olds are not surprised when an object that has been lowered inside a transparent container is not visible through the front of the container (Luo and Baillargeon, in preparation); and finally (6) 9-month-olds are not surprised when a tall object is fully hidden inside a short tube or under a short cover (Wang and Paterson, 2000).

How can we make sense of these results (see also Baillargeon, 1991, 1993, 1995)? If continuity and solidity principles constrain infants' interpretations of physical events, shouldn't they be able to readily detect all of these violations?

In this section, I first outline some of the assumptions my collaborators and I hold about infants' representations of physical events. Next, I discuss how limitations in infants' representations could lead to their failure to detect even salient continuity and solidity violations. Finally, I sketch out a possible experimental test of the approach proposed here.

How Do Infants Represent Physical Events?

My collaborators and I have developed a number of assumptions about infants' representations of physical events (e.g., see Aguiar and Baillargeon, in press; Hespos and Baillargeon, 2001b); three of these assumptions are described below.

A first assumption is that, when observing physical events, infants build *physical representations* that focus on the physical properties, displacements, and interactions of the objects within the events. (Infants no doubt build several representations simultaneously, for different purposes. For example, another representation might focus on the features of the objects in the events, and be used for recognition and categorization purposes—to ascertain whether these particular objects, or similar objects, have been encountered in the past; e.g., see Needham and Modi, 2000).

A second assumption is that infants' physical representations of events are by no means faithful copies of the events: they are abstract, functional descriptions that include some but not all of the physical information in the events.

Finally, a third assumption is that how much information infants include in their physical representations of events depends in part on their knowledge of the variables likely to affect the events. We suppose that, early in the representation process, infants categorize the event they are observing (e.g., as an occlusion or a containment event), and then access their knowledge of the event category selected. This knowledge specifies what variables should be attended to as the event unfolds—in other words, what information should be included in the physical representation of the event. To illustrate, this last assumption means that 3½-month-old infants who see an object being lowered behind a container (occlusion event) will include information about the relative heights and widths of the object and container in their physical representation of the event, because they have already identified height and width as occlusion variables. In contrast, 3½-month-old infants who see an object being lowered inside rather than behind a container (containment event) will not encode the relative heights and widths of the object and container, because they have not yet identified height and width as containment variables.[9]

A Case of Impoverished Physical Representations

If one accepts the assumptions discussed in the previous section, it becomes clear how infants might possess core continuity and solidity principles and still fail to detect salient violations of these principles. Infants' core principles, like all of their physical knowledge, can only operate at the level of their physical representations (i.e., infants do not apply their expectations directly to events, only to their representations of the events). It follows that, when infants bring to bear their continuity and solidity principles onto their physical representations of events, they will succeed in detecting violations of the principles *only* when the key information necessary to detect the violations is included in the representations. Infants' principles can only guide the interpretation of information that is included in their physical representations; information that has not been represented cannot be interpreted.

To illustrate how incomplete physical representations could lead infants to ignore violations of their continuity and solidity principles, consider one of the findings discussed earlier, that 3-month-old infants are not surprised when an object fails to appear between two screens connected at the bottom by a narrow strip (Aguiar and Baillargeon, in press; Baillargeon and DeVos, 1991; Luo, 2000). What is being suggested is that, when observing such an event, 3-month-old infants typically do not include information about the relative heights of the object and occluder in their physical representation of the event. Thus, when infants apply their continuity principle to their incomplete physical representation of the event, they have no basis for realizing that a portion of the object should be visible above the narrow strip between the screens.

To give another example, consider the finding that 4½- to 6½-month-old infants are not surprised when a tall object becomes fully hidden inside a short container (Hespos, 1998; Hespos and Baillargeon, 2001a). What is being suggested is that, when observing such an event, infants aged 6½ months and younger typically do not include information about the relative heights of the object and container in their physical representation of the event. Thus, when infants apply their continuity principle to their incomplete representation of the event, they cannot appreciate that a portion of the object should be visible above the container.

How Are Infants' Physical Representations Enriched?

I suggested in the previous section that young infants might possess continuity and solidity principles and still fail to detect violations of these principles because of incomplete physical representations. One important process by which infants' physical representations of events become more complete over time must be the identification of variables, as discussed in previous sections. After infants identify height as an occlusion variable, at about 3½ months of age (Baillargeon and DeVos, 1991), they begin to routinely include information about the heights of objects and occluders in their physical representations of occlusion events. Similarly, after infants identify height as a containment variable, at about 7½ months of age (Hespos, 1998; Hespos and Baillargeon, 2001a), they begin to routinely include information about the heights of objects and containers in their physical representations of containment events. (What makes it so certain that infants, once they have identified a variable, routinely include information about this variable in their physical representations, is that separate tests of sensitivity to a variable, conducted on different infants and often with different experimental events, consistently produce similar results; compare, for example, the positive results of Baillargeon and DeVos, 1991, and Hespos and Baillargeon, 2001a on height in occlusion events, and of Hespos and Baillargeon, 2001a and Wang and Paterson, 2000, on height in containment events).[10]

However, there might also be a process by which infants can be *temporarily* induced to include certain key information in their representations of physical events. What if, for example, 4½- to 6½-month-old infants could somehow be "primed" to include height information when representing containment events? This possibility is particularly intriguing because it suggests a direct test of the speculations advanced in the last section. According to these speculations, it should not really matter whether infants include information in a physical representation because (1) they have been primed to do so by the experimental context or (2) they have already identified the pertinent variable. In either case, the information, once represented, should be subject to infants' continuity and solidity principles, making it possible to detect violations of the principles. To return to our containment example, this means that 4½- to 6½-month-old infants who were induced to include height information in their physical representations of containment events *should* be surprised when shown a tall object being fully lowered inside a short container (recall that infants do not normally detect this violation until about 7½ months of age; Hespos and Baillargeon, 2001a). The infants' continuity principle would guide the interpretation of their (artificially enriched) representation, resulting in an enhanced performance at a younger age.

Although no investigation has yet attempted to prime infants' physical representations in just the way described here, a recent series of experiments by Wilcox and her colleagues (Wilcox, 1999; Chapa and Wilcox, 1998) suggests that such attempts will be effective. In preliminary experiments (Wilcox, 1999), infants saw an object move behind one side of a screen; after a pause, a different object emerged from behind the opposite side of the screen. The screen was either too narrow or sufficiently wide to hide the two objects simultaneously. The results indicated that, by 9½ months of age, infants showed surprise at the narrow-screen event when the objects on the two sides of the screen differed in size, shape, and pattern, but not color; only 11½-month-old infants showed surprise at the narrow-screen event involving a red and a green ball (red-green event). In subsequent experiments, Chapa and Wilcox (1998) attempted to induce 9½-month-old infants to include color information in their physical representation of the red-green event. The infants received two pairs of priming trials. In the first, a red cup was used to pour salt, and a green cup was used to pound a wooden peg; the second pair of trials was similar except that different red and green containers were used. After receiving these priming trials, the infants showed surprise at the red-green event. One interpretation of these findings, in line with the speculations above, is that the infants were primed to include color information in their physical representation of the red-green event; this added information then became subject to the infants' continuity and solidity principles, allowing them to detect the violation in the event.

Of course, there may be several different ways of priming infants to include key information in their physical representations of events. Suhua Wang and I have begun testing a very different approach, in which we capitalize on the fact that infants routinely include height or width information when representing some events (e.g., occlusion events), to induce them to include similar information when representing subsequent events (e.g., covering events) involving the same objects. For example, in one experiment, 8-month-old infants see a short or a tall cover standing next to a tall object. To start, the cover is pushed *in front of* the object; the tall cover occludes all of the object, the short cover only its bottom portion. Next, the cover is lifted and lowered *over* the object, until it is fully hidden. As mentioned earlier, Wang and Paterson (2000) found that 9-month-old infants are not surprised when a tall object becomes fully hidden under a short cover. This new experiment thus asks whether infants might detect this violation if first shown an occlusion event involving the same cover and object. Our reasoning is as follows: once infants have included the relative heights of the cover and object in their physical representation of the initial, occlusion event, they might be inclined to do the same in—or have this information available for—their physical representation of the subsequent, covering event. This information would then be subject to infants' core principles, making it possible to detect the violation in the short-cover event.

The preceding speculations hopefully make clear the potential interest of priming experiments. Assuming that priming effects can be produced, much research will be needed to find out, for example, what manipulations are helpful for priming variables and what manipulations are not; whether priming some variables improves infants' performance but priming others does not (i.e., priming variables not linked to core principles should have no immediate effect on infants' ability to detect violations); and finally, what are the long-term effects of successful priming experiences and how they compare to those of successful "teaching" experiences (as discussed earlier; Baillargeon, 1998, 1999). As a result of this research, we should learn a great deal more about the contents of infants' physical representations, the processes by which they can be enhanced, and the core principles that guide their interpretation.

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Notes

1. Preliminary data from experiments with Su-Hua Wang suggest that at 6½ months of age infants expect an object to be stable only if *over* half of its bottom surface is supported; by 8 months of age, infants have refined this rule and expect an object to be stable if *half or more* of its bottom surface is supported.

2. Recent data by Dan, Omori, and Tomiyasu (2000) suggest that, initially, infants expect an object whose middle section rests on a support to be stable, even when the section supported is very narrow (e.g., a pumpkin resting on a pencil-thin block). Over time, however, infants come to appreciate that a sufficient portion of the object's middle section must be supported for it to be stable.

3. It might be assumed that the lag reported here simply reflects the fact that young infants possess a concept of occlusion but not containment. However, this interpretation is unlikely. Recent findings (Hespos and Baillargeon, 2001b) indicate that, by 2½ months of age, infants already possess expectations about containment events. In particular, infants (1) believe that an object continues to exist

after it disappears inside a container and (2) expect the object to move with the container when displaced.

4. The phrase "when infants register these contrastive outcomes" is important because infants could of course be exposed to contrastive outcomes without actually registering the differences between them.

5. From the present perspective, a variable is thus akin to a dimension; conditions correspond to values on the dimension, with each value (or discernible range of values) being associated with a distinct outcome (hence the emphasis placed here on contrastive outcomes).

6. This discussion might lead readers to assume that the learning process as described here is primarily error-driven: infants notice that a rule (objects remain stable when released *on* supports) leads to incorrect predictions (objects do not always remain stable when released on supports), and set about correcting it. However, we mean our analysis to be more general. In some cases, infants will begin to notice contrastive outcomes from a different facet of an event, one they had largely ignored until then. For example, some time after infants realize that objects move when hit, they begin to notice that objects may move longer or shorter distances when hit; eventually, infants identify some of the variables responsible for these different outcomes (Kotovsky, 1994; Kotovsky and Baillargeon, 1998). A similar example has to do with the duration of occlusions—how long objects remain hidden when passing behind occluders (e.g., see Wilcox and Schweinle, submitted). The process of identifying variables is thus not always error-driven; in some cases, infants begin to notice new facets of events, and then identify the variables that contribute to them.

7. The distinction between qualitative and quantitative reasoning strategies is derived from computational models of everyday physical reasoning (e.g., Forbus, 1984).

8. Before leaving this section, I would like to address one common criticism of the notion that infants' learning mechanism is typically triggered by exposure to contrastive outcomes that cannot be explained or predicted by infants' current knowledge. This criticism is that infants are obviously capable of acquiring knowledge about objects in the absence of contrastive outcomes. For example, infants no doubt learn about the shapes and colors of bananas and carrots simply by repeated exposure to these objects. I fully agree that infants can learn facts about individual objects or categories of objects in the absence of contrastive outcomes (e.g., see Kotovsky and Baillargeon, 1998). What I would argue, however, is that (1) infants possess several different learning mechanisms, each with its own purpose and requirements for learning; and (2) the mechanism responsible for the acquisition of facts about specific objects and object categories (e.g., bananas are yellow) is different from the one responsible for the acquisition of facts about physical objects in general (e.g., objects typically fall when released in midair).

9. This discussion raises interesting questions about what basic information infants include in their physical representation of an event when they know no

variable about the event (or indeed possess no relevant event category). For example, what information do 2½-month-old infants, who know few if any variables, typically include in their physical representations of events? And what factors are responsible for these contents?

10. For a discussion of a situation in which infants who have identified a variable may nevertheless fail to reason correctly about it, see Aguiar and Baillargeon (2000) on perseveration and problem solving in infancy.

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