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Critical Thinking Questions

1. What leads the author to believe that maternal stress can cause development changes in a fetus?
2. Summarize the findings from animal studies on the role of prenatal maternal stress.
3. Describe the challenges and approaches for conducting research on prenatal stress in humans.
4. What does the author conclude about the state of the science when it comes to the role of prenatal maternal stress in humans?

Infants' Physical World

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Abstract

Investigations of infants' physical world over the past 20 years have revealed two main findings. First, even very young infants possess expectations about physical events. Second, these expectations undergo significant developments during the first year of life, as infants form event categories, such as occlusion, containment, and covering events, and identify the variables relevant for predicting outcomes in each category. A new account of infants' physical reasoning integrates these findings. Predictions from the account are examined in change-blindness and teaching experiments.

Keywords

infant cognition; physical reasoning; explanation-based learning

Over the past 20 years, my collaborators and I have been studying how infants use their developing physical knowledge to predict and interpret the outcomes of events. This article focuses on infants' knowledge about three event categories: occlusion events, which are events in which an object is placed or moves behind a nearer object, or occluder; containment events, which are events in which an object is placed inside a container; and covering events, which are events in which a rigid cover is lowered over an object (Baillargeon & Wang, 2002). I first summarize two relevant bodies of developmental findings, and then point out discrepancies between these findings. Next, I outline a new account of infants' physical reasoning that attempts to make sense of these discrepancies. Finally, I describe new lines of research that test predictions from this account.

All of the research reviewed here used the violation-of-expectation method. In a typical experiment, infants see an expected event, which is consistent with the expectation 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 indicates that they possess the expectation under investigation, detect the violation in the unexpected event, and respond to this violation with increased attention.

PRIOR FINDINGS

Beginnings

Infants as young as 2.5 months of age (the youngest tested to date) can detect some violations in occlusion, containment, and covering events (see Fig. 1). For

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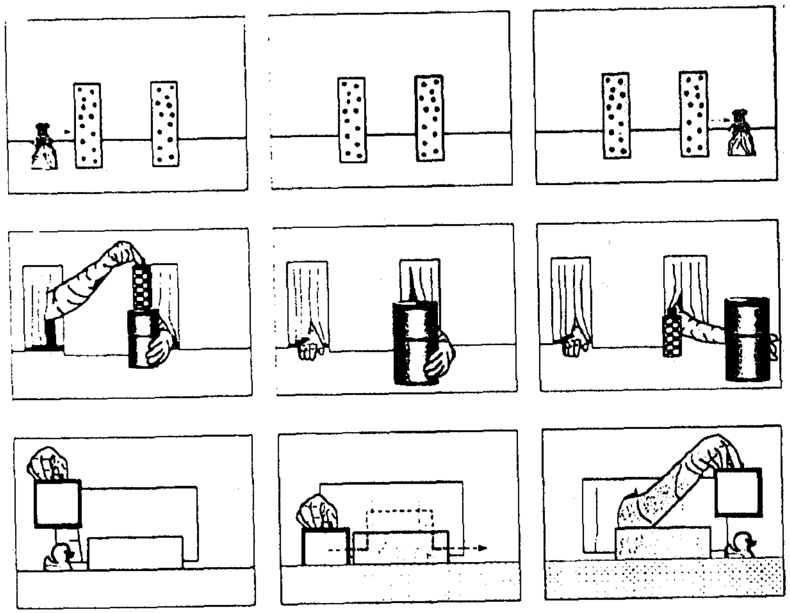

Fig. 1. Examples of violations detected by very young infants. The top row illustrates an occlusion violation: The toy mouse disappears behind one screen and reappears from behind the other screen without appearing in the gap between them (Aguiar & Baillargeon, 1999). The middle row illustrates a containment violation: The checkerboard object is lowered inside the container, which is then slid forward and to the side to reveal the object standing in the container's initial position (Hespos & Baillargeon, 2001b). The bottom row illustrates a covering violation: The cover is lowered over the toy duck, slid behind the left half of the screen, lifted above the screen, moved to the right, lowered behind the right half of the screen, slid past the screen, and finally lifted to reveal the duck (Wang, Baillargeon, & Paterson, in press).

example, in one occlusion experiment, 2.5-month-old infants saw a toy mouse disappear behind one screen and reappear from behind another screen. The infants detected the violation in this event, suggesting that they believed that the mouse continued to exist after it became hidden, and realized that it could not disappear behind one screen and reappear from behind another screen without appearing in the gap between them (Aguiar & Baillargeon, 1999).

In a containment experiment, 2.5-month-old infants saw an experimenter lower an object inside a container; the experimenter then slid the container forward and to the side to reveal the object standing in the container's initial position. The infants responded to this event with increased attention, suggesting that they believed that the object continued to exist after it became hidden, and realized that it could not pass through the closed walls of the container (Hespos & Baillargeon, 2001b).

In a covering experiment, infants aged 2.5 to 3 months saw a toy duck resting on the left end of a platform; the middle of the platform was hidden by a screen slightly taller than the duck. An experimenter lowered a cover over the duck, slid the cover behind the left half of the screen, lifted it above the screen, moved it to the right, lowered it behind the right half of the screen, slid it past the screen, and finally lifted it to reveal the duck. The infants detected the violation in this event, suggesting that they believed that the duck continued to exist after it became hidden, and expected it to move with the cover when the cover was slid but not lifted to a new location (Wang, Baillargeon, & Paterson, in press).

How do 2.5-month-old infants detect these and other (e.g., Luo & Baillargeon, in press; Spelke, Breinlinger, Macomber, & Jacobson, 1992; Wilcox, Nadel, & Rosser, 1996) occlusion, containment, and covering violations? It does not seem likely that very young infants would have repeated opportunities to observe all of these (or similar) events and to learn to associate each event with its outcome. Rather, it seems more likely, as suggested by Spelke (1994), that from an early age infants interpret physical events in accord with general principles of *continuity* (objects exist continuously in time and space) and *solidity* (for two objects to each exist continuously, the two cannot exist at the same time in the same space). Later in this review, I return to the question of whether these principles are likely to be innate or learned.

Developments

Although by 2.5 months of age infants already possess expectations about occlusion, containment, and covering events, much development must still take place in these expectations. Recent research has revealed two main findings. First, for each event category, infants identify a series of variables that enables them to predict outcomes more and more accurately over time. For example, at about 3.5 months of age, infants identify height as an occlusion variable: They now expect tall objects to remain partly visible when behind short occluders (Baillargeon & DeVos, 1991). At about 7.5 months of age, infants identify another occlusion variable, transparency: They now expect an object to remain visible when behind a clear, transparent occluder (Luo & Baillargeon, 2004).

Second, infants do not generalize variables across event categories: They learn separately about each category. When infants identify a variable in one event category weeks or months before they identify it in another category, striking lags can be observed in their responses to similar events from the two categories (see Fig. 2). For example, in one series of experiments, 4.5-month-old infants saw an experimenter lower a tall object either behind (occlusion condition) or inside (containment condition) a short container until only the knob at the top of the object remained visible above the container. The infants detected the violation in the occlusion but not the containment condition; further results indicated that only infants ages 7.5 months and older detected the violation in the containment condition (Hespos & Baillargeon, 2001a). In other experiments, 9-month-old infants watched an experimenter either lower a tall object inside a short container until it became fully hidden (containment condition) or lower a short cover—the container turned upside down—over the same object until it became fully hidden (covering condition). The infants detected the violation in the containment but not the covering condition; further results revealed that only infants ages 12 months and older detected the violation in the covering condition (Wang et al., in press). In yet other experiments, 7.5-month-old infants saw an object standing next to a transparent occluder (occlusion condition) or container (containment condition)

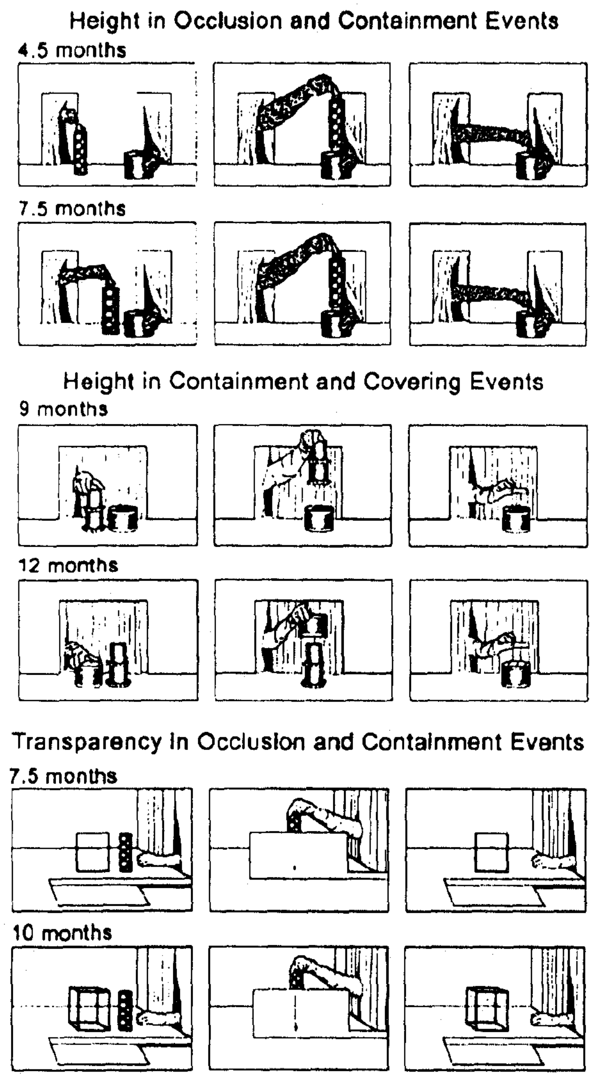

Fig. 2. Examples of lags in infants' reasoning about the same variable in different event categories. The top two rows illustrate the lag in infants' identification of the height variable in containment as opposed to occlusion events. Although 4.5-month-old infants detect the violation in the occlusion event, it is not until infants are about 7.5 months old that they detect the violation in the containment event (Hespos & Baillargeon, 2001a). The middle two rows illustrate the lag in infants' identification of the height variable in covering as opposed to containment events: Although 9-month-old infants detect the violation in the containment event, it is not until infants are about 12 months old that they detect the violation in the covering event (Wang, Baillargeon, & Paterson, in press). The bottom two rows illustrate the lag in infants' identification of the transparency variable in containment as opposed to occlusion events: Although 7.5-month-old infants detect the violation in the occlusion event, it is not until infants are about 10 months old that they detect the violation in the containment event (Luo & Baillargeon, 2004).

Next, a large screen hid the occluder or container, and then an experimenter lifted the object and lowered it behind the occluder or inside the container. Finally, the screen was lowered to reveal only the transparent occluder or container. The infants detected the violation in the occlusion but not the containment condition: only infants ages 10 months and older detected the violation in the containment condition (Luo & Baillargeon, 2004).

These results indicate that infants do not generalize variables from occlusion to containment or covering events, but learn separately about each event category. Thus, the height variable is identified at about 3.5 months in occlusion events, but only at about 7.5 months in containment events and 12 months in covering events. Similarly, the transparency variable is identified at about 7.5 months in occlusion events, but only at about 10 months in containment events.

A NEW ACCOUNT OF INFANTS' PHYSICAL REASONING

Discrepancies

The developmental evidence I have just discussed suggests that the expectations infants acquire about events are not event-general expectations that are applied broadly to all relevant events, but rather event-specific expectations. Infants do not acquire general principles of height or transparency: They identify these variables separately in each event category. But if infants are capable of acquiring only event-specific expectations, how could they possess event-general principles of continuity and solidity, and as early as 2.5 months of age? One possibility is that infants' learning mechanism is initially geared toward acquiring event-general expectations, but soon evolves into a different mechanism capable of acquiring only event-specific expectations. Another possibility, which I think more likely, is that infants' general principles of continuity and solidity are innate (Spelke, 1994).

Whichever possibility one chooses, difficulties remain. If infants interpret events in accord with general continuity and solidity principles (whether learned or innate), one might expect them to detect all salient violations of these principles. However, we saw that although some continuity and solidity violations are detected as early as 2.5 months, others are not detected until much later: Recall, for example, that infants younger than 7.5 months do not respond with increased attention when a tall object becomes hidden inside a short container, and that infants younger than 12 months do not respond with increased attention when a tall object becomes hidden under a short cover.

A New Account

A new account of physical reasoning (see Fig. 3) attempts to make sense of infants' early successes and late failures at detecting continuity and solidity violations (Baillargeon, 2002; Wang et al., in press). This account rests on four assumptions. First, when watching a physical event, infants build a specialized physical representation of the event that is used to predict and interpret its outcome. Second, all of the information, but only the information, included in the physical representation becomes subject to infants' general principles. Third, in

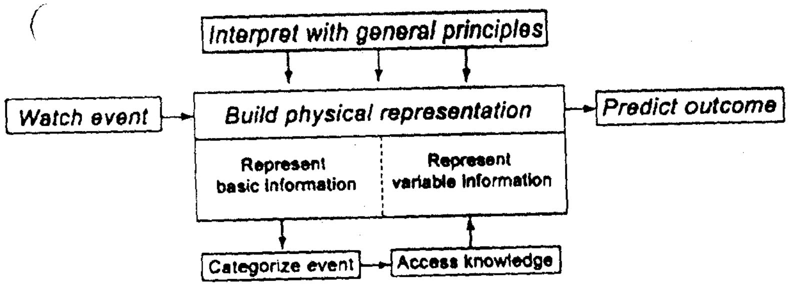

Fig. 3. A new account of physical reasoning in infancy (Baillargeon, 2002; Wang, Baillargeon, & Paterson, in press).

the first weeks of life, infants' physical representations are rather impoverished: When representing an event, infants typically include only basic spatial and temporal information about it. For example, when watching a containment event, infants represent that an object is being lowered inside a container. This information captures the essence of the event, but leaves out most of its details: whether the container is taller or wider than the object, whether it is transparent or opaque, and so on.

Fourth, as infants form event categories and learn what variables to consider in each category, they include information about these variables in their physical representations. When watching an event, infants represent the basic information about the event and use this information to categorize it. They then access their knowledge of the event category selected; this knowledge specifies the variables that have been identified as relevant to the category and hence that should be included in the physical representation. Going back to our example, infants who have identified height as a containment variable would include information about the relative heights of the object and container in their representation of the event; this information would then become subject to their general principles, enabling them to detect violations involving tall objects and short containers.

Thus, according to this reasoning account, even very young infants should detect continuity and solidity violations that involve only the basic information they can represent; and much older infants should fail to detect continuity and solidity violations that involve information about variables they do not yet include in their physical representations.

TESTS OF THE ACCOUNT

Change-Blindness Effects

According to the reasoning account, infants who have not yet identified a variable as relevant to an event category, and hence do not include information about this variable when representing events from the category, should be unable to detect surreptitious changes involving the variable; in other words, they should be blind to these changes. An experiment with 11- and 12-month-old infants tested this prediction; this experiment built on the findings that height is identified at about 3.5 months as an occlusion variable but only at about 12 months as a covering variable. The infants watched an experimenter lower a tall cover in front of (occlusion condition) or over (covering condition) a short object; next, the cover was removed to reveal an object as tall as the cover. Both the 11- and the 12-month-olds detected the change in the occlusion condition, but only the 12-month-olds detected the change in the covering condition. As predicted by the reasoning account, the 11-month-olds in the covering condition were blind to the surreptitious change in the height of the object (Wang & Baillargeon, 2004a).

Teaching Effects

Another prediction from the reasoning account concerns teaching effects. If infants could be taught a new variable in an event category, then they would include information about this variable when representing novel events from the category, enabling them to detect violations involving the variable earlier than they would otherwise. Wang and I recently attempted to teach 9.5-month-old infants the height variable in covering events (Wang & Baillargeon, 2004b).

What might be the key ingredients in a successful teaching experiment? The process by which infants typically identify a new variable in an event category is assumed to be one of explanation-based learning and to involve three main steps (e.g., Baillargeon, 2002). First, infants notice contrastive outcomes for the variable (e.g., they notice that when a cover is placed over an object, the object is sometimes fully and sometimes only partly hidden). Second, infants search for the conditions that relate to these outcomes (e.g., they detect that the object becomes fully hidden when it is shorter than the cover, and becomes partly hidden when it is taller than the cover). Finally, infants build an explanation for these condition-outcome data using their prior knowledge (e.g., infants' continuity and solidity principles specify that a tall object can extend to its full height inside a tall but not a short cover).

In line with this analysis, the infants in our experiment received three pairs of teaching trials. Each pair consisted of a tall- and a short-cover event. In each event, an experimenter rotated the cover forward to show its hollow interior, placed the cover next to a tall object (to facilitate height comparisons), and then lifted and lowered the cover over the object. The object became fully hidden in the tall-cover event, and partly hidden in the short-cover event. Different covers were used in the three pairs of trials. The infants next saw test events in which a novel tall (expected event) or short (unexpected event) cover was lowered over a novel tall object until it became fully hidden. The infants detected the violation in the short-cover event, suggesting that they were able to identify the height variable in covering events during the teaching trials. Positive results were also obtained when a 24-hr delay separated the teaching and test trials.

Subsequent experiments examined some of the assumptions behind our teaching trials. As expected, infants showed no evidence of learning when the teaching trials were modified so that they provided either no contrastive outcomes (the object was shorter and became fully hidden under the tall and short covers), no condition information (the cover was never placed next to the tall object on the apparatus floor, making it difficult for infants to compare their heights), or no explanation (false bottoms inside the covers—revealed when the covers were rotated forward—rendered them all equally shallow). The infants tested with the shallow covers were exposed to the same condition-outcome data as in our original teaching experiment, but could not make sense of the fact that the tall object became fully hidden under the tall but shallow covers.

FUTURE DIRECTIONS

I have focused on a small portion of infants' physical world: their knowledge of occlusion, containment, and covering events. Similar analyses can be offered for infants' knowledge of other event categories, such as support and collision events (e.g., Baillargeon, 2002). Together, this evidence provides strong support for the account of infants' physical reasoning presented here, and more generally for the notion that both event-general and event-specific expectations contribute to infants' responses to physical events.

In future research, my collaborators and I plan to expand our reasoning account in several directions. Infants recognize that events involving inert and self-moving objects may have different outcomes, so a complete account should explain infants' reasoning about both event and object categories. Furthermore, to make sense of events as they unfold, infants must not only represent individual events but also integrate successive events, so a complete account should specify how infants link successive physical representations.

We are also beginning to explore possible connections between infants' physical reasoning system and other cognitive systems. For example, infants can at first include in their physical representations only objects they directly see or have seen; only after some time are they able to infer the presence of additional objects, perhaps when connections are forged with a separate problem-solving system. Similarly, infants are at first limited to reasoning qualitatively about continuous variables (e.g., height or width); only after some time do they become able to engage in quantitative reasoning about these variables, perhaps when connections are formed with a system for representing absolute spatial information. Finally, infants may not reveal some of their physical knowledge in action (as opposed to violation-of-expectation) tasks until suitable connections are established with the system responsible for planning and executing actions (Berthier et al., 2001).

As researchers continue to make progress in understanding how infants attain and use their physical knowledge, we come closer to unveiling the complex architecture that makes it possible for them to learn, so very rapidly, about the world around them.

Recommended Reading

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Critical Thinking Questions

1. What are occlusion, containment, and covering, and how do they inform us about how infants understand physical events?
2. What is the violation-of-expectation method and why is it used in research with infants? Why would this same method not be used in studies with adults?
3. What does change blindness tell us about an infant's expectation for an event?