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18

Continuity, Competence, and the Object Concept

Elizabeth Spelke and Susan Hespos

In 1967, Mehler and Bever reported a groundbreaking study of number concepts and logical abilities in young children. Their studies focused on Piaget's famous "number conservation" task, which had revealed a striking discontinuity in children's cognitive performance. When children about five years of age are asked to judge the relative numerosities of two rows of objects that differ in length and spacing, they often respond on the basis of length rather than number; when older children are given the same task, in contrast, they focus consistently on number. This developmental change was taken by Piaget to reflect the emergence of a new system of logical operations and a new set of concepts, including the first true number concepts. To test this interpretation, Mehler and Bever presented two- to five-year-old children with a child-friendlier task that was logically identical to Piaget's. After judging that two rows had the same number of candies, children watched as the arrays were shortened, lengthened, or changed in number and then they were invited to take one row of candies. For comparison, the same children also were tested with clay pellets and were asked, as in Piaget's studies, which of two rows had more pellets. With the candies test, children chose the more numerous row at all ages; with the pellets, they succeeded at the youngest and oldest ages but failed at about four years.

To account for the task-dependent performance that they discovered, Mehler and Bever invoked the distinction between competence and performance and argued for continuity in children's competence. Children have an understanding of number that emerges early in the third year, if not before, that is continuously present thereafter, and that reveals itself in simple and motivating situations such as the candies task. They suggested that four-year-old children's failure in the pellets task reflected their discovery of a perceptual strategy—using length to judge number—that temporarily masked their underlying competence in the less motivating pellets task.

Many cognitive scientists now criticize developmental explanations like Mehler and Bever's that invoke the competence-performance distinction and the continuity thesis (e.g., see Thelen and Smith, 1993; Rumelhart and McClelland, 1986; Munakata et al., 1997). The pattern of task-dependent behavior discovered by Mehler and Bever nevertheless is one of many that continue to challenge developmental psychologists, who must explain why children of a given age appear to command a given concept or reasoning process in one context but not in another. Today, task-dependent performance patterns are puzzling investigators in domains ranging from earlier-developing number concepts (infant success: Wynn, 1998; preschool failure: Mix, Huttenlocher, and Levine, 1996), to theory of mind (success before three years: Clements and Perner, 1994; failure until four years: Perner and Wimmer, 1988), to naive physics (success in infancy: Baillargeon, 1995; failure in preschoolers: Hood, 1995; Berthier et al., 2000). But perhaps the most famous and vexing example of task-dependence has arisen in studies of infants' ability to represent hidden objects: an ability that appears to be present as early as two months when infants are tested by preferential looking methods, but that appears to be absent as late as 18 months when children are tested by manual search methods. This last example, we believe, provides a good test case for contrasting approaches to cognitive development.

Evidence for Task-Dependence in Object Concept Development

Young infants' patterns of preferential looking provide evidence that they represent the continued existence of objects that move from view (see Baillargeon, 1993, and Spelke, 1998, for reviews). For example, when five-month-old infants observe first a single object that is occluded by a moving screen and then a second object that joins the first behind the screen, they subsequently look longer when the screen is lowered to reveal one object (an unexpected outcome to adults, but one that is superficially familiar since only one object ever was visible in the scene at any given time) than when it is lowered to reveal two objects (Wynn, 1992). This extensively replicated finding (Baillargeon, 1994; Koechlin, Dehaene, and Mehler, 1998; Simon, Hespos, and Rochat, 1995; Uller et al., 1999; see also Spelke et al., 1995; Xu and Carey, 1996) provides evidence that infants continued to represent the existence of each object within the scene after it was occluded. As a second example, when 2½-month-old infants observe an object hidden either inside or behind a container and then see the object again when the container is moved to the side, they react differently depending on how the object is hidden (Hespos and Baillargeon, 2001a). Although both scenes look identical at the time the container is moved, infants look longer if the object had originally been placed inside it. This finding is one of many providing evidence that infants reason about the behavior of the hidden object in accord with a solidity principle, inferring that the hidden object could not pass directly through the side of the container (see Baillargeon, 1995).

In contrast to these findings, infants fail to retrieve hidden objects until about nine months of age in the simplest situations (Piaget, 1954), and their search for hidden objects sometimes fails to be guided by inferences about solidity until they are more than two years old (Berthier et al., 2000; Hood, 1995; Hood et al., 2000). For example, when 2½-year-old children view a ball rolling down a ramp toward a partly hidden barrier and are encouraged to retrieve the ball by reaching through one of four doors in a screen that covers the ramp and most of the barrier, they choose among the doors at random, apparently oblivious to the relation between the ball, ramp, and barrier (Berthier et al., 2000). Although many of the search tasks that infants fail are more complex than the preferential looking tasks at which they succeed, this is not always the case. Preferential looking experiments and reaching experiments produced contrasting findings, for example, when infants were tested on the same object permanence task at the same ages with the two measures (e.g., see Ahmed and Ruffman, 1998). What accounts for these discrepancies?

Hypothesis 1: Preferential Looking Reflects Purely Perceptual Representations

Some investigators have proposed that preferential looking methods reveal relatively shallow representations and processes. For example, such methods may assess only infants' sensory abilities (e.g., see Haith and Benson, 1997; Bogartz, Shinsky, and Speaker, 1997), midlevel visual abilities (e.g., see Scholl and Leslie, 1999), implicit knowledge (e.g., see Moscovitch, 1992), or representations divorced from action (Bertenthal, 1996; Spelke, Vishton, and von Hofsten, 1995). Further experiments, however, cast doubt on all these proposals. First, young infants have been found to reach for objects in the dark: a pattern that provides evidence that they represent the permanence of objects that lose their visibility due to darkness, and that this representation guides reaching actions (Hood and Willatts, 1986; Clifton et al., 1991). Moreover, young infants sometimes show very similar looking and reaching patterns when the task of reaching for an occluded object is simplified.

In particular, Hespos and Baillargeon (submitted) investigated whether infants would demonstrate, in a simple action on an occluded object, the same representational capacity that was previously revealed in preferential looking tasks. One set of experiments focused on infants' knowledge about occlusion and containment events, and more specifically infants' understanding that the height of an object relative to an occluder or container determined how much of the object could be hidden behind or inside it. Previous research (Hespos and Baillargeon, 2001b) indicated that at four months, infants look significantly longer at an event where an object is completely hidden behind an occluding screen that is only half as tall as the object than at an event in which the object was hidden behind a screen of equal height. In contrast, infants fail to look longer when the same object is hidden inside a short occluding container until 7½ months. To test whether infants would exhibit the same developmental pattern in an object-retrieval task, infants of 5½ and 7½ months of age were presented with a tall frog and encouraged to play with it. After a few seconds, the frog was removed and the infants were presented with two occluding screens or containers that had frog legs wrapped around the sides of them so that the feet were sticking out in front and could be grasped directly. The screens and containers were identical except for their height: one was tall enough to conceal the entire frog behind it, whereas the other was one-third the needed height. After the infants' attention was drawn to each occluding object, the apparatus was moved toward the infant, whose reaching was observed.

Infants of both ages reached significantly more often for the frog behind the tall screen, even though, in a control condition, they showed no intrinsic preference for the tall screen. These reaching patterns provide evidence that the infants appreciated that only the tall screen could conceal the frog. In contrast, infants reached more often for the frog inside the tall container at 7½ but not 5½ months of age. These experiments, and additional experiments on knowledge about support events, suggest that the representations of object occlusion, containment, and support emerge on the same developmental time course in preferential looking and reaching tasks. This knowledge evidently does not reside in representations that are purely sensory, implicit, or otherwise divorced from goal-directed action.

Hypothesis 2: Piagetian Search Tasks Reflect Developing Capacities for Means-Ends Coordination

A second family of explanations for infants' task-dependent performance with respect to occluded objects appeals to the demands that Piaget's search tasks place on the infant's developing actions. In particular, infants may reach for visible objects before they reach for occluded objects because the former can be retrieved by a simple, direct reach, whereas the latter can be retrieved only if the infant reaches around the occluder or removes it: actions that may overtax infants' capacities for means-ends coordination (e.g., see Baillargeon, 1993; Spelke et al., 1992). Young infants' successful reaching for objects in the dark and for objects with a visible, graspable part (the occluded frogs with protruding legs) is consistent with these explanations, because the nonvisible objects could be retrieved in these cases by a simple, direct reach. Motor limitations also could explain infants' success in Ahmed and Ruffman's (1998) preferential looking tasks and failure in their parallel reaching tasks, because the tasks differ in the motor demands they place on infants. Further experiments cast doubt on these explanations, however, because young infants sometimes fail to use object representations to guide their search for hidden objects even in tasks that put no undue demands on their action systems. These studies focused on six-month-old infants' predictive reaching for moving objects.

When a continuously visible, out-of-reach object begins to move smoothly toward them, infants of four months and beyond typically will attempt to grab it, initiating their reach before the object enters reaching space and aiming ahead of the object's current position so as to intercept it when it comes within their range (von Hofsten, 1980; von Hofsten et al., 1998). Accordingly, Spelke and von Hofsten (in press) placed an occluder over a portion of the path of the object on some trials, such that the object moved briefly out of view before it entered infants' reaching space. Because the occluder was out of reach, it did not serve as a barrier to infants' reaching: infants could catch the object by carrying out the same direct, predictive reach as in the trials on which the object was fully visible. The occluder therefore prevented infants from seeing the object but did not affect the motor actions needed to retrieve the object. Based on the hypothesis that limits to infants' object search reflected limits to motor control, we initially predicted that infants would succeed in reaching predictively for the temporarily occluded object.

Infants' head tracking in this situation suggested that they represented the hidden object and quickly learned to predict where it would reappear (von Hofsten, Feng, and Spelke, 2000). Contrary to our predictions, however, infants almost never reached for the object on trials with the occluder (Spelke and von Hofsten, in press). Although infants could have retrieved the object by executing the same direct reach that they used on trials without the occluder, they failed to do this when the object was hidden during the time that the reach would have begun. We conclude that limits to infants' means-ends coordination cannot fully account for infants' failure to search for hidden objects.

Hypothesis 3: Representations of Objects Are More Precise When the Objects Are Visible; the Loss of Visibility Therefore Causes a Performance Decrement on Any Task for Which Precision Is Required

Why do looking and reaching tasks sometimes yield different patterns of performance (e.g., see Ahmed and Ruffman, 1998; Spelke and von Hofsten, in press) and at other times yield the same patterns of performance (e.g., see Hespos and Baillargeon, submitted)? We propose that a critical variable concerns the precision of the representation that a task requires. When reaching or preferential looking tasks require a precise representation, then infants' performance will be impaired by occlusion; when reaching or preferential looking tasks demand only an imprecise representation, then occlusion may have little effect on performance.

Consider, for example, the Ahmed and Ruffman (1998) experiments. In their preferential looking experiment, infants viewed an object that moved successively behind two screens and then was revealed either behind the last screen where it was hidden (consistent with continuity) or behind the other screen (inconsistent). To detect the inconsistency, infants had to represent that the object existed behind a given screen but did not need to represent the object's shape, height, or exact location. In their reaching experiment, in contrast, infants viewed an object that moved in the same sequence behind the two screens, and then they reached for it. To guide an appropriate reach for the object, infants had to represent not only that it existed behind the screen but also its shape, size, and exact location: without this information, appropriate reaching is impossible. If infants' representations of occluded objects are imprecise, therefore, they may succeed at the first task but fail the second, resorting instead to an action strategy ("do what worked before") not unlike the perceptual strategies described by Mehler and Bever (1967).

In contrast, consider the Hespos and Baillargeon (2001b, submitted) studies described above. In both the preferential looking and the reaching experiments, infants must represent the crude height of the frog in relation to the heights of the two occluders. Because the infant can obtain the frog by reaching for its visible foot, however, neither the reaching task nor the preferential looking task requires a precise representation of the hidden frog's location or shape. The two tasks therefore put equivalent demands on the precision of the infant's object representations and give equivalent findings.

Evidence that object representations are less precise when objects are occluded, and that this loss in precision affects infants' performance in preferential looking as well as reaching tasks, comes from studies by Baillargeon. In one well-known series of experiments, Baillargeon used a rotating screen task to test infant's representation of hidden objects (see

Baillargeon, 1993, for review). Infants were habituated to a screen that rotated through a 180-degree arc. In the test trials, a box was placed in the path of the rotating screen. In the consistent event, infants saw the screen come into contact with the box and reverse direction. In a set of inconsistent events, infants saw the screen rotate through part or all of the space that was occupied by the box. Infants as young at 3½ months old looked significantly longer when the screen rotated through all of the space occupied by the box, providing evidence that they represented the hidden box. In contrast, 4½-month-old infants failed to look longer at the inconsistent event when the screen rotated through 80 percent of the space occupied by the box, and 6½-month-old infants failed to look longer when it rotated through 50 percent of that space, although they did look longer at the 80 percent violation. Taken together, these studies suggest that there is a developmental increase in the precision of infants' representations of occluded objects. Experiments with visible reminders (a visible box next to an identical occluded box) further support this interpretation (Baillargeon, 1993).

The hypothesis that infants' object representations are more precise when objects are visible than when they are hidden could explain why infants reach predictively for moving, visible objects and look predictively at moving, temporarily occluded objects, but fail to reach predictively for moving, temporarily occluded objects. To catch a moving object, one must represent considerable information about the object, including its size, shape, path, and speed of motion. When the object is continuously visible, infants' representations evidently are adequate to guide appropriate reaching. When the object is hidden, however, their representation of its properties may become too imprecise to guide effective attempts to intercept it. Even an imprecise representation of an occluded object may suffice, however, to guide a look in the correct direction.

The visibility hypothesis likely applies not only to the object representations formed by infants but also to those formed by adults. To test whether loss of visibility impairs the precision of object representations throughout development, we ran an experiment on adults, modeled on the studies of predictive reaching in infants. The adults stood on the right side of a large board containing a target (the same display used in the reaching studies with infants) that moved by means of a hidden, motor-controlled magnet from the left side of the board in a linear path halfway across the board. The task for the adults was to extend the linear trajectory of the target to the right side of the board and to mark the point at the end of the board where the object could be intercepted. There were six different linear trajectories similar to those used with infants. In the first part of the experiment, the object was continuously visible. In the second part of the experiment, we introduced a large screen that occluded the second half of the object's trajectory—roughly the same part of the trajectory that was occluded for infants. The adults viewed the first part of the trajectory, saw the target pass under the occluder, and again made predictions about the endpoint of the trajectory. The adults were significantly more accurate in the visible condition than in the occluder condition. For adults, as for infants, object representations are more precise when objects are visible.

Despite its advantages, the visibility hypothesis cannot explain why babies reach more for objects in the dark than for occluded objects. This finding motivates the next hypothesis.

Hypothesis 4: Representations of Objects Are More Precise When No Other Objects Compete for Attention

Munakata and Stedron (in press) propose that infants' object representations, like those of adults, are competitive: the more an infant attends to one object, the less precise will be his or her representations of other objects. When an object is hidden behind an occluder, therefore, it may suffer a double loss of precision due both to its lack of visibility and to competition from its visible occluder. In contrast, an object that vanishes into darkness suffers a loss of precision only because of its lack of visibility and so should be represented more precisely than an occluded object, though less precisely than a visible one.

Jansson and von Hofsten (submitted) conducted an initial test of Munakata and Stedron's competition hypothesis by comparing infants' predictive reaching for objects that were obscured by darkness vs. occlusion. Six-month-old infants reached for a moving object on a series of trials in which the object was fully visible and then on a series of trials in which it was made invisible for one of three durations by one of two means: occlusion vs. darkness. The experiment revealed three effects. First, infants reached most frequently and accurately when the object was continuously visible, consistent with the visibility hypothesis. Second, reaching was more impaired by longer than by shorter periods of invisibility. Third, reaching was more impaired by occlusion than by darkness. All these findings are consistent with the thesis that reaching requires a precise representation of the goal object and that both loss of visibility and competition from a visible occluder reduce the precision of infants' representations.

Like the visibility hypothesis, the competition hypothesis likely applies to adults as well as infants. In our study of adults' predictive reaching, we investigated this possibility by presenting the same subjects who participated in the visible and occluder conditions with a third condition, in which the lights in the room were extinguished during the object's motion. The period of darkness was timed such that the object was visible and invisible at the same times and places in the darkness condition as in the occluder condition. Performance during the darkness condition, however, was significantly better than performance during the occluder condition. These findings support Munakata and Stedron's proposal that object representations are competitive both for adults and for infants.

Thus far, we have attempted to explain infants' performance on object permanence tasks by proposing that infants represent objects from very early ages, and that the precision of their representations is affected by two factors that also affect the precision of object representations in adults: visibility and competition. Together, the visibility and competition hypotheses support a continuity theory of object concept development, whereby infants and adults show common representational capacities and mechanisms. The continuity view nevertheless continues to face one problem: How can it account for developmental changes in infants' performance on object permanence tasks? To address this question, we propose one developmental change in object representations.

Hypothesis 5: Object Representations Show Qualitative Continuity over Human Development but Become Increasingly Precise as Infants Grow

Although adults reach best for fully visible objects, next best for objects obscured by darkness, and least well for objects obscured by occluders, they manage to reach for objects in all these cases. Why, in contrast, do

young infants fail to reach at all when objects are occluded? We suggest that infants' basic capacities for representing objects are constant over development, but that their object representations increase gradually in precision as they grow. Young infants may fail to reach for occluded objects under many circumstances because the precision of their representations is too low to guide the hand effectively. At older ages, reaching still is less accurate when objects are occluded (as, indeed, it is for adults), but the precision of object representations rises to the point where reaching can be attempted. Gradual, quantitative changes in the precision of object representations therefore give rise to a qualitative change in infants' performance on Piaget's search tasks.

The thesis that object representations become more precise with growth and development is supported by Baillargeon's (1991, 1993) developmental studies of infants' reactions to inconsistent partial rotations in the rotating screen task. It gains further plausibility from studies of perceptual development, which have documented developmental increases in the precision of perceptual representations for a variety of tasks, including grating acuity, contrast sensitivity, motion detection, and auditory localization (see Kellman and Arterberry, 1998, for review). Research in progress is testing this hypothesis further by investigating developmental changes, from six to twelve months, in infants' predictive reaching for visible and temporarily invisible objects. As both the age of the infant and the duration of interrupted visibility vary, we expect to see variations in performance suggestive of a continuous process of development, rather than a qualitative, age-related shift caused by the emergence of a new representational capacity. Initial findings are consistent with this prediction.

Conclusions

Both Piaget's number conservation tasks and his object permanence tasks reveal striking developmental changes in children's performance. In both cases, however, we believe that children's performance depends on cognitive capacities that are continuous over human development. In particular, human infants have a capacity to represent occluded objects as early as two months of age, and that capacity undergoes no qualitative reorganization as children grow.

The evidence for ontogenetic continuity discussed here complements evidence for phylogenetic continuity in the capacity to represent objects. In particular, monkeys represent objects similarly to human infants both in preferential looking and in object search tasks (Hauser, MacNeilage, and Ware, 1996; Antinucci, 1990), and they progress through Piaget's stage sequence more rapidly than human infants do: a pattern that undermines views likening infants to scientists who form and change their theories (see Carey and Spelke, 1996). Most dramatically, newly hatched chicks have now been shown to pass the object search tasks that human infants fail until nine months of age (Regolin, Vallortigara, and Zanforlin, 1995). These findings make little sense if one thinks that search for hidden objects depends on the construction of a new conception of the world. They mesh well, however, with the view that basic mechanisms of object representation are constant over much of evolution and ontogeny, that their expression depends in part on the developing precision of representations, and that this development occurs at different rates for different species.

Because infants' actions on objects do change over development, the thesis that infants have a constant capacity for object representation requires that one distinguish competence from performance and that one analyze the factors that limit infants' performance at young ages, as did Mehler and Bever (1967). Our attempt to provide this analysis here suggests that two factors—visibility and competition—limit actions on objects in the same ways for infants and for adults. Infants and adults appear to form more precise representations of visible than of hidden objects, and they appear to maintain more precise representations when an object disappears into darkness than when it disappears behind a visible occluder. This analysis suggests there is developmental continuity not only in representational capacities but also in some of the factors that influence the expression of those capacities.

Jacques Mehler has spent a good part of his career conducting research based on the thesis that one can observe in infants the core of capacities we continue to exercise as adults. Guided by this thesis, he has crafted studies of infants that shed light on central aspects of speech and language in adults. Object concept development, however, has long seemed to provide a major challenge to any continuity theory. In Piaget's day, infants were thought to progress from an egocentric universe centered on their own actions to an objective world in which they viewed themselves as one entity among many. In more recent times, developmental changes in actions on objects were proposed to reflect other qualitative changes, including an emerging coordination in the functioning of multiple visual pathways (Bertenthal; 1996; Spelke et al., 1995), a progression from qualitative to quantitative reasoning (Baillargeon, 1995), an emerging capacity for recall (Mandler, 1992), or an emerging propensity for generating explanations (Baillargeon, 1998). In contrast to all these possibilities, we suggest that the nature and limits to human representations of objects are the same for infants and adults, and only the precision of those representations gradually changes. If we are right, then Mehler and Bever's approach to task-dependence, emphasizing developmental continuity and the competence-performance distinction, is as fitting today as it was in the 1960s.

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19

Infants' Physical Knowledge: Of Acquired Expectations and Core Principles

Renée Baillargeon

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 sa-

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