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ScienceDirect
Cognition 107 (2008) 304–316
COGNITION
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Brief article

Young infants' actions reveal their developing knowledge of support variables: Converging evidence for violation-of-expectation findings

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Received 19 July 2006; revised 28 May 2007; accepted 22 July 2007

Abstract

Violation-of-expectation (VOE) tasks have revealed substantial developments in young infants' knowledge about support events: by 5.5 months, infants expect an object to fall when released against but not on a surface; and by 6.5 months, infants expect an object to fall when released with 15% but not 100% of its bottom on a surface. Here we investigated whether action tasks would reveal the same developmental pattern. Consistent with VOE reports, 5.5- and 6.5-month-old infants were more likely to reach for a toy that rested on as opposed to against a surface; and 6.5- but not 5.5-month-olds were more likely to reach for a toy with 100% as opposed to 15% of its bottom on a surface. Infants at each age thus used their support knowledge to determine whether the toys were likely to be retrievable or to be attached to adjacent surfaces and hence irretrievable. These and control findings extend recent evidence that developmental patterns observed in VOE tasks also hold in action tasks, and as such provide further support for the view that VOE and action tasks tap the same physical knowledge.

Keywords: Infant cognition; Physical knowledge; Action task

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0010-0277/$ - see front matter
doi:10.1016/j.cognition.2007.07.009

1. Introduction

Infants' ability to make sense of physical events develops substantially during the first year of life, and psychologists have long been interested in elucidating the nature and causes of this development (e.g., Baillargeon, 1993; Bower, 1974; Bruner, 1968; Leslie, 1994; Piaget, 1954; Spelke, 1988). Research over the past 15 years has brought to light two salient patterns in the development of infants' physical reasoning. One pattern is that infants form distinct events categories (e.g., occlusion, containment, and support events) and learn separately about each category, leading at times to striking décalages in their responses to similar events from different categories (e.g., Aguiar & Baillargeon, 2003; Casasola, Cohen, & Chiarello, 2003; Hespos & Baillargeon, 2001a; McDonough, Choi, & Mandler, 2003; Quinn, 2007; Wang & Baillargeon, 2006; Wang, Baillargeon, & Paterson, 2005; Wilcox & Chapa, 2002). The other pattern is that, for each event category, infants identify a series of variables that enables them to predict outcomes more and more accurately over time (e.g., Aguiar & Baillargeon, 2002; Baillargeon, Needham, & DeVos, 1992; Hespos & Baillargeon, 2001a; Kotovsky & Baillargeon, 1998; Luo & Baillargeon, 2005; Sitskoorn & Smitsman, 1995; Wang, Kaufman, & Baillargeon, 2003; Wilcox, 1999). These two patterns were first uncovered in violation-of-expectation (VOE) tasks, which rely on infants' tendency to look longer at events that violate, as opposed to confirm, their expectations. Over the past few years, converging evidence from action tasks has begun to accumulate for the first pattern (e.g., Hespos & Baillargeon, 2006; Li & Baillargeon, in preparation; Wang & Kohne, in press). Here we sought converging evidence from action tasks for the second pattern.

There are several reasons to seek evidence in action tasks for developmental patterns identified in VOE tasks. First, such corroborative evidence strengthens accounts of infants' physical reasoning that incorporate these patterns (e.g., Baillargeon, Li, Luo, & Wang, 2006; Baillargeon, Li, Ng, & Yuan, in press; Spelke & Hespos, 2001). Second, observing similar responses in VOE and action tasks makes clearer the conditions under which infants' physical knowledge successfully guides their actions (e.g., Berthier et al., 2001; Diamond & Lee, 2000; Goubet & Clifton, 1998; Hespos & Baillargeon, 2006; Hespos, Gredebäck, Von Hofsten, & Spelke, 2007; Hofstadter & Reznick, 1996; Hood & Willatts, 1986; Kochukhova & Gredebäck, in press; Ruffman, Slade, & Redman, 2005; Shinskey & Munakata, 2003). Finally, obtaining similar results in VOE and action tasks helps alleviate concerns that VOE tasks overestimate infants' cognitive abilities (e.g., Bogartz, Shinskey, & Schilling, 2000; Bogartz, Shinskey, & Speaker, 1997; Cashon & Cohen, 2000; Haith, 1998; Munakata, McClelland, Johnson, & Siegler, 1997; Rivera, Wakeley, & Langer, 1999; Shinskey, Bogartz, & Poirier, 2000; Thelen & Smith, 1994). We return to these issues in Section 4.

In the next section, we review some of the evidence from VOE and action tasks for the first developmental pattern described above; we next introduce the present research, which used similar action tasks to examine the second pattern.

1.1. First developmental pattern

According to the first developmental pattern discussed in the last section, infants learn separately about each event category. When weeks or months separate the identification of the same variable in different categories, striking décalages can be observed in infants' responses to similar events from the different categories (for reviews, see Baillargeon et al., 2006, in press). The first experimental evidence for this pattern came from a VOE task comparing infants' reasoning about the variable height in containment and occlusion events (Hespos & Baillargeon, 2001a). In one experiment, 4.5-month-olds were assigned to a containment or an occlusion condition and saw two test events. In the containment condition, a hand grasped a knob at the top of a tall object; next to the object was a tall (tall event) or a short (short event) container. In both events, the hand lifted the object and lowered it inside the container until only the knob remained visible. The infants in the occlusion condition saw similar events except that the back half of each container was removed, leaving only the front half to serve as a rounded occluder. The infants in the occlusion condition looked reliably longer at the short than at the tall event, but those in the containment condition looked equally at the two events. In subsequent experiments, 5.5-, 6.5-, and 7.5-month-olds were tested with the containment condition events; only the 7.5-month-olds detected the violation in the short event. These and control data thus revealed a marked décalage in infants' identification of the variable height in occlusion and containment events (for an explanation of this lag, see Hespos & Baillargeon, 2001a, 2001b; Wang, Baillargeon, & Brueckner, 2004).

Would infants show a similar decalage in an action task? To find out, 6- and 7.5-month-olds were first shown a tall frog (Hespos & Baillargeon, 2006). Next, the frog was placed behind a large screen, which was then removed to reveal a short and a tall container (containment condition) or a short and a tall occluder (occlusion condition); two frog feet protruded from the bottom of each container or occluder. The occluders were identical to the fronts of the containers. In the occlusion condition, both the 6- and the 7.5-month-old infants reached reliably more for the tall than for the short occluder; in the containment condition, in contrast, only the 7.5-month-old infants reached reliably more for the tall than for the short container. These and control results thus confirmed the décalage observed in the VOE task (Hespos & Baillargeon, 2001a).

1.2. Second developmental pattern

According to the second developmental pattern described earlier, for each event category, infants identify a series of variables that enables them to predict outcomes within the category more and more accurately over time (for reviews, see Baillargeon et al., 2006, in press). The present research asked whether the same pattern would be observed in action tasks.

The point of departure for our research came from VOE findings on the development of infants' knowledge about support events (e.g., Baillargeon, 1995; Baillargeon et al., 1992; Li, Baillargeon, & Needham, 2006; Needham & Baillargeon, 1993). At 3.5–4.5 months of age, infants expect an object to fall when released a short distance from the side of a platform, but they have no expectation as to whether it should remain stable or fall when released against the platform. By 5.5 months of age, infants have identified *type of contact* as a support variable: they are now surprised if an object remains stable when released against but not on a platform. However, infants tend to look equally if the object remains stable with either 15% or 100% of its bottom surface on the platform. By 6.5 months of age, infants have identified *proportion of contact* as a support variable, and are now surprised if the object remains stable with only 15% of its bottom surface on the platform. The present research asked whether a similar developmental pattern would be found in action tasks with 5.5- and 6.5-month-olds. Specifically, we tested whether the 5.5-month-olds' actions would reveal their knowledge of the variable type of contact, but not proportion of contact, whereas the 6.5-month-olds' actions would reveal their knowledge of both variables.

Infants at both ages were assigned to a type-of-contact or an proportion-of-contact condition (see Fig. 1). The infants were first given a small toy and encouraged to play with it. Next, the toy was placed behind a large screen, which was then removed to reveal an apparatus with two identical copies of the toy. The experiment examined whether the infants would bring to bear their knowledge of support – as revealed in the VOE experiments discussed above – to determine which toy they should reach for. In each condition, one toy could only remain stable if it were attached to the apparatus and hence was not retrievable; the other toy was adequately supported by the surface on which it rested and hence was potentially retrievable (control conditions to rule out baseline preferences are presented in Section 3).

In the *type-of-contact* condition, the apparatus consisted of a vertical surface, or wall, with a platform across the bottom. The two toys stood at the same height against the wall, equidistant from the midline; because the platform was higher on one half of the wall than on the other, one toy rested on the platform and the other lay well above it. We reasoned that if the infants wanted a toy and brought to bear their knowledge of support to determine which toy they could retrieve, then both the 5.5- and the 6.5-month-olds should realize that (1) the toy above the platform could only remain stable against the wall if it were attached to it and (2) the toy on the platform was adequately supported by the platform and hence was potentially retrievable. The infants in both age groups should thus reach for the toy on the platform.

In the *proportion-of-contact* condition, the infants saw a similar apparatus except that the two toys rested on two small identical platforms; one toy had its entire bottom surface (100%) on its platform, and the other toy had only a small amount (15%) of its bottom surface on its platform. We reasoned that if the infants brought to bear their knowledge of support to determine which toy they could retrieve, then the 6.5-month-olds should realize that (1) the toy with 15%-support could only remain stable if it were attached to its platform, and (2) the toy with 100%-support was adequately supported by its platform and hence was potentially retrievable. These older infants should thus reach for the toy with 100%-as opposed to 15%-support. In contrast, the 5.5-month-olds should view

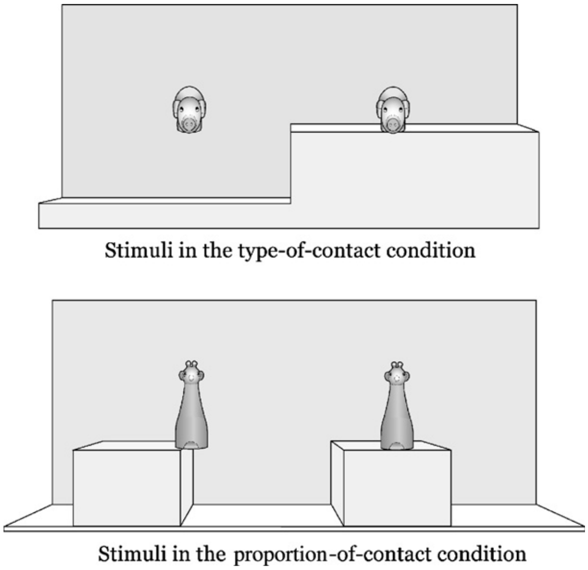

Fig. 1. Stimuli used in the present research. At the start of the trial, a small squeak toy was brought from behind the screen on the test table and given to the infant to play with; next, the toy was returned behind the screen, which was then removed to reveal two identical copies of the toy. Each infant thus saw three identical copies of the same toy; toys were selected at random from a cast of pink pigs, yellow giraffes, blue hippos, and pink elephants (all made by WinTech). The approximate dimensions of the toys were 5 cm high (9.5 cm high for the giraffes), 3.5 cm wide, and 8 cm long. The screen was 30 cm high and 66 cm wide and, like the table, was covered with blue contact paper. Top: In the type-of-contact condition, the apparatus consisted of a foam board wall 29.5 cm high, 58 cm wide, and 0.7 cm deep. At the bottom of the wall was a platform 5 cm deep; half of the platform was 12.5 cm high and half 3 cm high. The entire apparatus was covered with patterned contact paper. The two toys were attached to the wall by concealed magnets and were positioned 12 cm from the bottom of the wall, with their centers 11 cm on either side of the midline. Thus, one toy rested on the higher half of the platform, and the other lay well above the lower half. On the opposite side of the wall was an identical platform except that its high and low halves were reversed, to counterbalance the position of the retrievable toy across infants. Because the objects were 18.5 cm apart, the infants did not actually have a front view of each object: rather they saw the front and right side of the left object, and the front and left side of the right object, and could thus determine from the available perceptual information that each object was positioned against the wall. As the apparatus was moved closer to the infants, this perceptual information became even more explicit. Bottom: In the proportion-of-contact condition, the apparatus consisted of a foam board wall 26 cm high, 61 cm wide, and 0.7 cm deep that stood centered on a thin base 0.7 cm high, 61 cm wide, and 25.5 cm deep. At the bottom of the wall, aligned with the front of the base, were two small identical platforms, each 8 cm high, 11.5 cm wide, and 12.5 cm deep. The entire apparatus was covered with contact paper. One toy stood on each platform, aligned with its front edge; the toy with 100%-support was attached to the center of its platform with double-sided tape, and the toy with 15%-support was attached to its platform by a concealed thin metal strip. One platform was positioned 12.25 cm from the midline and the other 5.25 cm from the midline; the positions of the platforms allowed the two toys to stand with their centers 11 cm on either side of the midline. On the opposite side of the wall were identical platforms except that their relative positions were reversed, to counterbalance the position of the retrievable toy across infants.

both toys as adequately supported, since both rested on a platform, and they should thus perform at chance.

2. Method

2.1. Participants

Participants were 68 healthy, term infants, 34 male and 34 female, and included 34 5.5-month-olds (range: 4 months, 16 days to 5 months, 28 day, $M = 5$ months, 12 days), and 34 6.5-month-olds (range: 6 months, 1 day to 7 months, 18 days, $M = 6$ months, 22 days). Another three infants were eliminated because they never reached for a toy. At each age, 16 infants were assigned to the type-of-contact condition, and 18 to the proportion-of-contact condition.

2.2. Procedure

Each infant sat on a parent's lap at the test table in a cut-out area 30 cm wide by 25 cm deep; the experimenter stood on the opposite side of the table. The screen was centered on the table, 42 cm from and parallel to the top of the cut-out area. Parents were instructed to hold their infant at the hips and to remain silent and neutral.

Each infant received a single trial. The experimenter first brought a toy from behind the screen and encouraged the infant to play with it. After about 10 s (sometimes it took longer to pry the toy from the infant's hands), the experimenter returned the toy behind the screen. Next, the experimenter removed the screen (and the toy, surreptitiously) from the table to reveal the apparatus with its two identical copies of the toy. The experimenter slid the apparatus forward until it stood 42 cm from the cut-out area, beyond the infant's reach. The experimenter then tapped on the platform on either side of each toy; tapping proceeded from left to right or right to left across the apparatus. Next, the experimenter slid the apparatus toward the infant, stopping just at the edge of the infant's reaching space, to encourage reaching with one hand instead of two and thus force a choice. The infant was given 30 s to respond (most infants responded immediately); during that time, the experimenter looked at the center of the apparatus to avoid inadvertently cueing the infant. The trial ended when the infant touched a toy. The left/right position of the retrievable toy and the direction of tapping were counterbalanced across infants.

Two cameras recorded the infant's reaching behavior: one captured a side view and one captured an aerial view. The images of both cameras were combined using a video mixer. Two independent coders analyzed edited copies of the videotapes (see below) and determined whether each infant reached for the toy on the left or right; there was no disagreement between the coders.

Preliminary analyses revealed no significant effects of sex, toy position, or tapping direction; the data were therefore collapsed across these factors in subsequent analyses.

3. Results

In the type-of-contact condition, 14/16 5.5-month-olds and 14/16 6.5-month-olds reached for the retrievable toy (cumulative binomial probability, $p < .0025$ for each

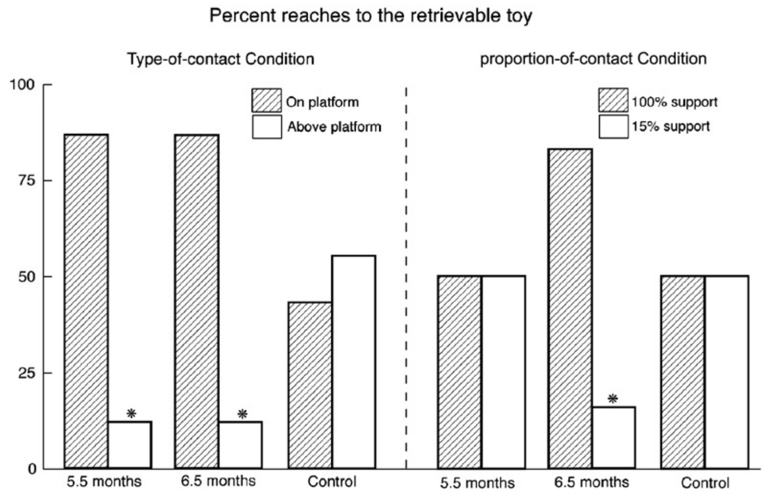

Fig. 2. Percent reaches to the retrievable toy in each age group and condition. The trial ended as soon as the infant touched a toy; two coders determined which toy the infant had touched. Three infants (one 6.5- and two 5.5-month-olds in the proportion-of-contact condition) grazed a toy en route to grasp the other toy fully; the coders agreed that the infants' intention was to get the toy they grasped fully, so their responses were coded as such. Asterisks indicate significant differences ($P < .01$ or better).

age group). In the proportion-of-contact condition, 15/18 6.5-month-olds ($p < .004$), but only 9/18 5.5-month-olds ($p > .50$) reached for the retrievable toy. The performance of the older and younger infants in the proportion-of-contact condition differed reliably, $\chi^2_1 = 4.5$, $p < .05$ (see Fig. 2).

Type-of-contact control condition. Most of the infants in the type-of-contact condition (28/32 infants) reached for the toy on the platform, suggesting that they realized it was retrievable whereas the other toy was not. However, another interpretation was that the infants simply preferred to reach for objects on horizontal surfaces rather than for objects against vertical surfaces. To examine this alternative interpretation, we ran a control condition identical to the type-of-contact condition, with one exception. Before moving the apparatus toward the infant, the experimenter lifted the apparatus and tilted it forward until it lay face down, 15 cm above and parallel to the top of the table (the toys were attached to the apparatus and did not fall). The experimenter then returned the apparatus to its upright position on the table and proceeded as before. Our rationale was that if the infants in the type-of-contact condition simply preferred reaching for objects on horizontal surfaces, then the infants in the control condition should show the same preference and again reach for the toy on the platform. On the other hand, if the infants in the type-of-contact condition reasoned about which toy was retrievable, then the infants in the control condition should realize that, since the toy on the platform did not fall when the apparatus was tilted forward, then, like the toy above the platform, it must be attached to its adjacent surfaces and irretrievable. Because neither toy was retrievable, we expected the infants to reach for either toy at random (as one might reach for an attractive doorknob, to inspect it manually rather than to recover it).

Participants were 16 5.5- to 6.5-month-olds (range: 4 months, 25 days to 7 months, 17 days, $M = 6$ months, 4 days). Because the videotapes were edited to include only the end portion of each trial, beginning when the apparatus was slid toward the infant, coders could not determine whether the infant belonged to the type-of-contact or the control condition. Only 7/16 infants (3/8 5.5-month-olds and 4/8 6.5-month-olds) reached for the toy on the platform ($p > .50$). This result differed reliably from that of each age group in the type-of-contact condition, $\chi^2 = 6.79$, $p < .01$.

Proportion-of-contact control condition. Most of the 6.5-month-olds in the proportion-of-contact condition (15/18) reached for the toy with 100%-support, suggesting that they realized that it was retrievable whereas the other toy was not. To confirm that these older infants did not simply prefer to reach for objects with 100%-support, we again ran a control condition in which the experimenter tilted the apparatus forward.

Participants were 18 6.5-month-olds (range: 6 months, 7 days to 7 months, 21 days, $M = 6$ months, 23 days). Only 9/18 infants reached for the toy with 100% support ($p > .50$); this performance differed reliably from that of the 6.5-month-olds in the proportion-of-contact condition, $\chi^2 = 4.5$, $p < .05$.

4. Discussion

In the present research, 5.5- and 6.5-month-olds reached reliably more for a toy resting on as opposed to against a surface; and 6.5- but not 5.5-month-olds reached reliably more for a toy with 100% as opposed to 15% of its bottom on a surface. These and control results confirm VOE findings that type of contact is identified as a support variable by 5.5 months of age, and proportion of contact by 6.5 months of age. The present results also confirm our recent finding that developmental patterns observed in VOE investigations of infants' physical knowledge also hold in action tasks (Hespos & Baillargeon, 2006), and extend this finding to a new developmental pattern. In Hespos and Baillargeon (2006), we tested the claim that infants sometimes identify the same variable at different ages in different event categories; in the present research, we tested the claim that within each event category infants identify a series of variables that enables them to predict outcomes more and more accurately over time.

Together, these results provide strong support for the view that VOE and action tasks tap the *same* physical knowledge (e.g., Baillargeon et al., in press; Hespos et al., under review). Further support for this view comes from recent experiments in which 9-month-old infants were "taught", through exposure to appropriate observations, the variable height in covering events; this variable is typically not identified until about 12 months of age (Wang & Baillargeon, 2006; Wang et al., 2005). Following exposure to the teaching observations, infants (1) were surprised in a VOE task when a tall object became fully hidden under a short but not a tall cover (Wang & Baillargeon, in press), and (2) searched for a tall object under a tall but not a short cover (Wang & Kohne, in press).

If VOE and action tasks tap the same physical knowledge, then why do infants sometimes reveal physical knowledge in VOE tasks that they fail to reveal in action tasks? Investigators have identified several factors, having to do with various facets of motor control, which contribute to these discrepancies (e.g., Diamond & Gilbert, 1989; Diamond & Lee, 2000; van der Meer, van der Weel, & Lee, 1994). However, there are also situations where infants possess sufficient motor control to perform the required actions but do not, suggesting that cognitive limitations underlie their poor performance. As an example, consider the long-standing controversy surrounding young infants' failure to search for hidden objects: when a toy is covered with a cloth, for example, infants younger than about 8 months typically make no attempt to lift the cloth and grasp the toy (e.g., Diamond, 1985; Piaget, 1954; Willatts, 1984). Piaget (1954) attributed this failure to a lack of object permanence: he believed that young infants did not search for hidden objects because they did not realize that objects continue to exist when out of sight. Subsequent researchers argued that this explanation was unlikely, because young infants succeeded at VOE tasks involving hidden objects (e.g., Baillargeon, 1986; Baillargeon & Graber, 1987; Baillargeon, Spelke, & Wasserman, 1985; Spelke, Breinlinger, Macomber, & Jacobson, 1992); instead, they proposed that young infants' failure to search stemmed from an inability to plan and execute means-end search actions (e.g., Baillargeon, 1993; Baillargeon, Graber, DeVos, & Black, 1990; Diamond, 1991; Goubet & Clifton, 1998; Willatts, 1997). In time, other researchers countered that means-end difficulties could not be the only factor at play, because young infants remained more likely to retrieve partly than fully hidden objects even when means-end demands were equated or reduced (e.g., Munakata et al., 1997; Shinskey, 2002; Shinskey & Munakata, 2001; Shinskey et al., 2000); these authors concluded that VOE tasks overestimated young infants' abilities, and that their failure to search reflected either an inability to represent hidden objects, as Piaget (1954) had suggested, or an inability to form representations strong enough to support search actions (e.g., Munakata et al., 1997; Shinskey, 2002; Shinskey & Munakata, 2001; Shinskey et al., 2000).

The debate over young infants' failure to search continued unabated until recently, when a new account suggested a possible solution to the controversy (e.g., Berthier et al., 2001; Boudreau & Bushnell, 2000; Keen & Berthier, 2004; Keen, Carrico, Sylvia, & Berthier, 2003). This new account, termed the cognitive-load account, assumes that infants' information-processing resources are initially limited and improve gradually with age; that the processing demands of any action task depend on both (1) the difficulty of the physical reasoning involved and (2) the difficulty of the actions involved; and that infants may fail at an action task when the *combined* demands of the task overwhelm their limited resources. Thus, according to the cognitive-load account, the reason why young infants fail at search tasks is not that they cannot represent hidden objects (since they demonstrate that they can do so in VOE tasks), or that they are unable to plan and execute appropriate actions (since they demonstrate that they can do so in tasks with partly hidden objects), but that the combined demands of the task overwhelm their limited processing resources. The cognitive-load account predicts that infants should perform better in search tasks when (1) the difficulty of the physical reasoning involved is reduced, and/or

(2) the difficulty of the actions involved is reduced, and there is growing evidence supporting both of these predictions (e.g., Berthier et al., 2001; Goubet & Clifton, 1998; Hespos et al., 2007; Hofstadter & Reznick, 1996; Hood & Willatts, 1986; Jonsson & von Hofsten, 2003; Keen & Berthier, 2004; Keen et al., 2003; Kochukhova & Gredebäck, 2007; Lockman, 1984; Ruffman et al., 2005; Shinskey & Munakata, 2003; Shinskey & Munakata, 2005).

The cognitive-load account also helps make clear why the young infants in Hespos and Baillargeon (2006) and in the present research readily demonstrated their physical knowledge in their actions: these tasks required only direct reaches toward stationary fully or partly visible objects (recall that frog legs protruded from each container or occluder in Hespos and Baillargeon (2006), and as such were unlikely to overcome infants' limited information-processing resources.

We have argued that VOE and action tasks tap the same physical knowledge; that under minimal task demands – such as those used here – similar performances should be expected in the two types of tasks; and that differences in performance, when they occur, may sometimes be explained in terms of discrepancies in cognitive load. In future research, we hope to better specify why certain tasks carry a greater cognitive load than others, what mechanisms help explain these differences, and how additional processing resources become available with development.

Acknowledgments

This research was supported by grants from the National Institute of Child Health and Human Development to the first (National Research Service Award HD-08124) and second (HD-021104) authors. We thank Rebecca Bloch, Laura Kerlin, Anna Lane, and Tiffany Warren for their help with the data collection and coding, and Glenn Roisman for his help with the statistical analyses. We also thank the parents who kindly agreed to have their infants participate in the research.

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