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Research Article

Five-Month-Old Infants Have Different Expectations for Solids and Liquids

Susan J. Hespos, Alissa L. Ferry, and Lance J. Rips

Northwestern University

ABSTRACT—*Many studies have established that 2-month-old infants have knowledge of solid objects' basic physical properties. Evidence about infants' understanding of nonsolid substances, however, is relatively sparse and equivocal. We present two experiments demonstrating that 5-month-old infants have distinct expectations for how solids and liquids behave. Experiment 1 showed that infants use the motion cues from the surface of a contained liquid or solid to predict whether it will pour or tumble from a cup if the cup is upended. Experiment 2 extended these findings to show that motion cues lead to distinct expectations about whether a new object will pass through or remain on top of a substance. Together, these experiments demonstrate that 5-month-old infants are able to use movement cues and solidity to discriminate a liquid from an object of similar appearance, providing the earliest evidence that infants can reason about nonsolid substances.*

By the time children are 2 years old, they expect solid objects and nonsolid stuff to behave differently. Solid objects often keep their shape over changes in position, but nonsolids, such as water or sand, often deform as they move. Accordingly, 2-year-olds are willing to generalize the name of a solid object to similarly shaped objects, even when the objects have different material composition. But they generalize the name of a nonsolid substance to substances of the same material, despite differences in shape (Imai & Mazuka, 2007; Soja, Carey, & Spelke, 1991). The substances tested in the studies yielding these findings were nonsolid particulate materials, such as sand, or nonsolid gels, creams, or liquids. In the experiments reported here, we used water as a nonsolid substance because it is the most pervasive nonsolid that infants are likely to encounter.

Solids and nonsolids divide the physical world in a fundamental way. In order to deal with nonsolid substances rather than solid objects, one must adjust one's methods of holding and retaining them, of transporting them, of navigating in or around them, of ingesting them, and of executing many other practical actions with them. In this article, we focus on two underlying attributes typically used to define solid objects: surface motion and penetrability (Spelke, 1990). Solid objects usually retain their shape when they move, and they resist penetration by other solids. Nonsolid substances, such as liquids, defy object-hood because their surfaces move (liquids deform to fill the space allotted), and they are penetrable (in that an object can pass through them).

When do children begin to appreciate these critical differences? Many studies have established that even at the age of 2 months, infants have knowledge of solid objects' basic physical properties, though their beliefs about individual properties have different developmental trajectories (Aguiar & Baillargeon, 1999; Hespos & Baillargeon, 2001a, 2001b; Needham & Baillargeon, 1993; Wang, Baillargeon, & Paterson, 2005). But evidence about infants' understanding of nonsolid substances (e.g., sand or liquid) is relatively sparse and equivocal. On the one hand, several studies suggest that noncohesive items, like piles of sand or blocks, are difficult for infants to follow over gaps in time (Chiang & Wynn, 2000; Huntley-Fenner, Carey, & Solimando, 2002). For example, Huntley-Fenner et al. showed 8-month-old infants a pile of sand, then concealed the pile behind a screen, and, finally, poured a second pile of sand behind a nearby but spatially separated screen. In this situation, adults would expect to see two piles of sand if the screens were taken away. However, when the two screens were removed, the infants spent no more time looking at a display containing just one pile than they did at a display containing two. With similar-looking solid objects, though, infants performed as expected in

Address correspondence to Susan J. Hespos, Psychology Department, 2029 Sheridan Rd., Evanston, IL 60208, e-mail: hespos@northwestern.edu.

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this paradigm, staring longer at the one-object display than at the two-object display.

On the one hand, results like these hint that infants may have so little knowledge of (or so little ability to process) nonsolid substances that they are unable to predict a substance's continued presence when it is briefly out of sight. Infants may have specialized mechanisms for picking out solid objects and following them as they move (Kahneman, Treisman, & Gibbs, 1992; Pylyshyn, 2001), and these mechanisms may lend a cognitive advantage that makes solids easier to encode and retain in memory. Later-developing means may be required for encoding nonsolids, and until these methods are in place, infants may rapidly forget nonsolids. Perhaps children need the support of language to make representations of nonsolids accessible or salient. Many natural languages distinguish countable from noncountable entities by means of specific linguistic markers. English, for example, marks countable entities with count nouns (e.g., *ice cubes*) and count quantifiers (e.g., *many*), but noncountable entities with mass nouns (e.g., *water*) and mass quantifiers (e.g., *much*). The linguistic distinction between countable and noncountable markers does not correlate perfectly with the distinction between solids and nonsolids; for example, one can use both the count noun *cows* and the mass noun *cattle* to refer to the same groups of objects. Nevertheless, a rough correlation does exist, and it is possible that children require this linguistic support before they can treat nonsolids in a distinctive way.

On the other hand, infants have plenty of experience dealing with substances. Encounters with substances like water and milk are probably universal for infants, although the specific substances may vary across cultures and climates (e.g., snow vs. sand). Furthermore, infants clearly find substances fascinating. They will play for extended periods splashing water in the bath or smearing baby food over the tray of their high chair. In line with these impressions, some recent studies indicate infants have the ability to maintain expectations about substances (Baillargeon & Kolstad, 1995, cited in Baillargeon, 1995; Gao, Levine, & Huttenlocher, 2000; vanMarle, 2004). In one experiment, for example, Gao et al. showed 9-month-olds a transparent container that was one-fourth full of red liquid. The experimenter then hid the container behind a screen and, as the infants watched, poured another half-container of liquid into the hidden container. When the screen was subsequently removed, the infants looked longer if the level of liquid in the original container had not changed (i.e., if the container was still one-fourth full) than if it appeared three-fourths full. These findings provide an existence proof that infants in the 1st year of life can discriminate differences in quantities of nonsolid substances and can anticipate when these quantities should change. Nevertheless, there is evidence that even minor procedural changes can disrupt infants' success in such tasks (vanMarle, 2004).

Nearly all the research on infants' understanding of nonsolid substances has focused on infants' ability to track substances over occlusion, as in the studies just described. Such tasks necessarily involve interpretational ambiguities because memory demands come into play; that is, the infants have to remember the state of the hidden contents in order to be surprised when those contents reappear. In addition, the manner in which the substances are contained or partitioned, the infants' familiarity with the types of substances used, and other variables may contribute to infants' difficulties in these tasks. All these factors can obscure how much infants understand about the nature of substances, although the exact role of these factors in particular experiments is often unclear. We return to a discussion of some of these factors in the General Discussion.

Gaining insight into what infants understand about nonsolid substances will shed new light on the mental mechanisms that underlie people's ability to deal with everyday physical entities. Our aim in the present study was to determine how much infants know about how liquids respond to basic physical laws, and, in particular, to determine whether infants can use motion cues on the surface of a liquid or a solid to predict the later behavior of the same item. We tested whether showing infants the surface motion of a liquid will lead them to expect other attributes of motion (Experiment 1) or penetrability (Experiment 2).

EXPERIMENT 1

In Experiment 1, we created a task in which there was no occlusion and no unfamiliar transformations. Unlike objects, liquids maintain a constant horizontal surface that is independent of the orientation of their containers. Tip a cup containing a solid chunk of ice, and the top surface of the ice stays parallel to the base of the cup, but tip a cup containing the same volume of water, and the water will tend to remain horizontal. If infants can distinguish a liquid from a solid on the basis of this difference, they may be able to project additional properties of these substances. They may expect that a liquid will pour from a cup if the cup is upended, whereas a solid will tumble from the cup. We tested 5-month-old infants because they were too young to have a productive grasp of linguistic markers for countable and noncountable entities, but old enough to have had some experience with liquids (e.g., water in a bath).

Method

Participants

The participants in Experiment 1 were 32 healthy, full-term infants (21 male and 11 female), ranging in age from 4 months 18 days to 5 months 16 days (M = 5 months 1 day). Half the infants were assigned to the *liquid* condition; the other half, to the *solid* condition. Five additional infants were tested but eliminated from the final analysis, 3 because of fussiness and 2 because they looked the maximum amount of time on every test trial.

We obtained infants' names from commercial mailing lists. The participants' parents were contacted by letter and were given a T-shirt or book as a gift. The ethnicity of the sample was 80% non-Hispanic and 20% Hispanic. The racial makeup of the

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sample was 70% White, 7% Asian, 2% Black or African American, and 13% multiracial; the remaining 8% of parents chose not to indicate their demographic information.

Apparatus and Stimuli

Parents sat in a chair facing an opening in the front of a wooden display box. The opening revealed a stage that displayed all stimulus objects. The back wall had two rectangular openings covered with cloth fringe. The experimenter manipulated objects on the stage by reaching through these openings, as shown in Figure 1. A screen that hid the stage from view was lowered between trials.

A small hole in the front face of the stage contained a camera that captured a video image of the infant's face. Two research assistants in a separate room viewed this image. Each researcher depressed a computer button when the infant attended to the objects on stage and released the button when the infant looked away. Xhab software (Pinto, 1996) recorded looking times and calculated when the habituation criteria had been met.

The stimuli consisted of four 0.59-L clear plastic "glasses," 0.23 L of water dyed blue, and a 0.23-L solid made of polyester resin that was visually identical to the blue water when the water occupied an upright, stationary position in the glass.

Events

When the screen went up at the start of a habituation trial (see Fig. 1), there was a single plastic glass on the stage. The experimenter's hand grasped the glass, tilted it to the left (1 s), and in a smooth motion rolled the glass on the rim of its base over a 5-s count. Next, the glass was returned to the upright position (1 s); this action was followed by a pause (1 s). This 8-s cycle was repeated continuously until the trial ended. In the liquid condition, infants saw habituation trials in which the glass contained blue water; hence, they saw the corresponding motion of the liquid as the glass rotated. In the solid condition, infants saw habituation trials in which the glass contained the blue solid in the bottom, and, consequently, there was no movement of the solid relative to the glass when the glass was rotated.

Two types of test trials were presented in alternation to all participants (see Fig. 1). On the solid trials, two transparent glasses were on stage when the screen went up. One glass was empty, but the other contained the blue solid. The experimenter grasped each glass (1 s) and tilted the glasses toward each other

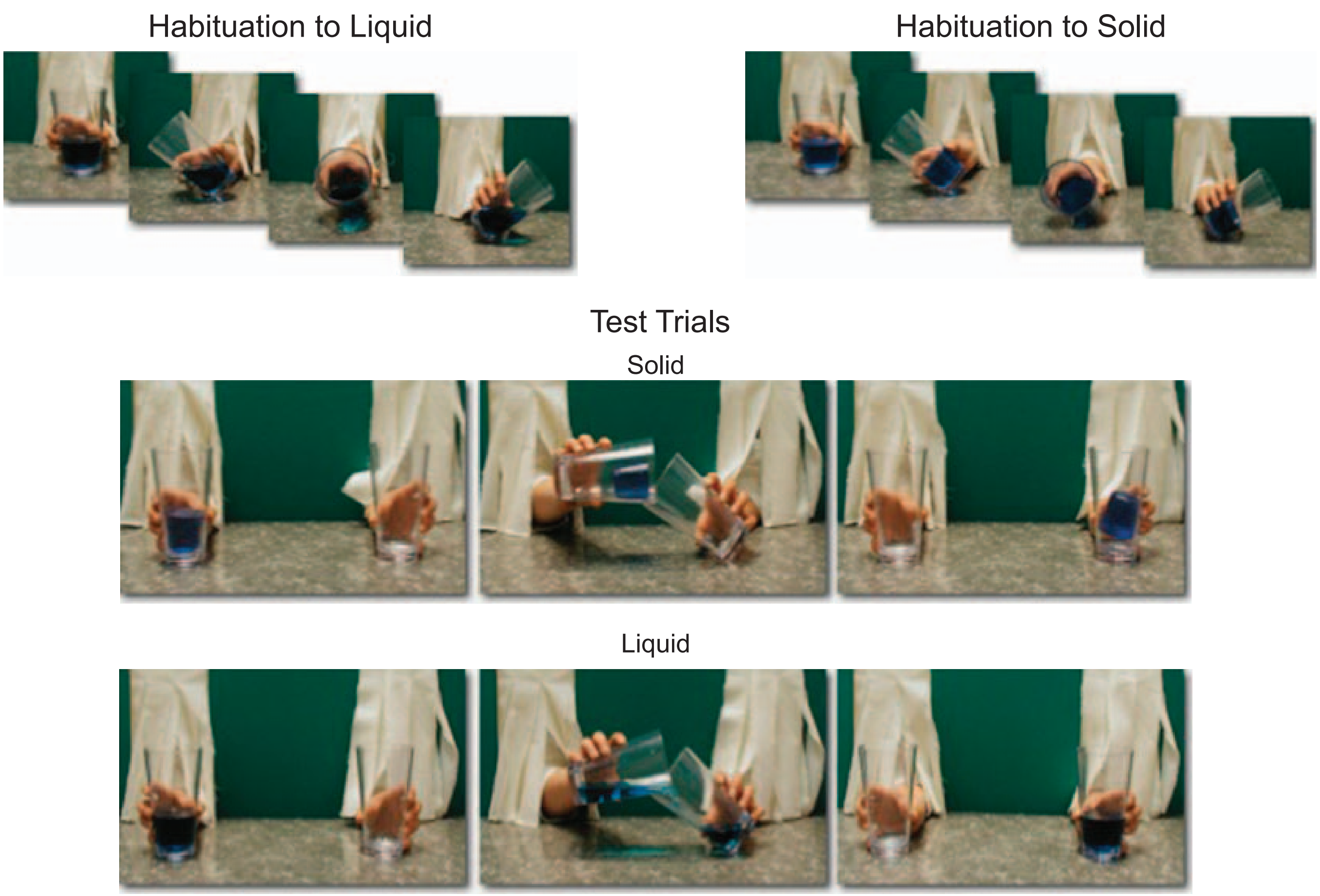

Fig. 1. Schematic illustration of the habituation and test trials in Experiment 1. Each infant saw either the solid or the liquid event during habituation. All infants received both the liquid and the solid test trials, presented in alternation. See the text for details.

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(1 s). Then, the solid tumbled from one glass to the other (5 s). The glasses were then returned to their initial positions (1 s), and the 8-s cycle was repeated continuously until the trial ended. On the liquid trials, the sequence of events was the same, but the contents of the glass consisted of a liquid instead of a solid, and the liquid was poured between the glasses.

Procedure

During the experiment, infants sat on their parent's lap in front of the apparatus. Parents were asked to refrain from interacting with the infants during the experiment, and to close their eyes during the test trials. Each trial ended when the infant either looked away for 2 consecutive seconds after having looked at the event for at least 2 s or looked at the event for 60 cumulative seconds without looking away for 2 consecutive seconds. A computer determined the end of the trial and signaled the experimenter to lower the screen. The habituation criterion was a decline of at least 50% in total looking duration from the first three to the last three habituation trials (or a maximum of nine trials). The average number of trials to reach criterion was seven. Each infant viewed six test trials, alternating between liquid and solid trials. The type of test event shown first and whether the left or right glass was full at the beginning of a trial were counterbalanced across infants. Interobserver agreement was determined for looking durations for all infants and averaged 95%.

Preliminary analyses revealed no significant effect of sex or test-trial order on the infants' looking times; we therefore collapsed across these variables in subsequent analyses.

Results

Figure 2 presents the mean looking times on the habituation and test trials. For each infant, we calculated mean looking time for novel test events (solid trials if the infant had habituated to liquid events, liquid trials if the infant had habituated to solid events) and familiar test events (solid trials if the infant had habituated to solid events, liquid trials if the infant had habituated to liquid events). Twenty-six of the 32 infants looked longer at the novel test trials than at the familiar test trials ($p_{rep} > .99$, binomial comparison). Across all participants, the average looking times were 37.07 s (SD = 16) for the novel events and 28.44 s (SD = 14.5) for the

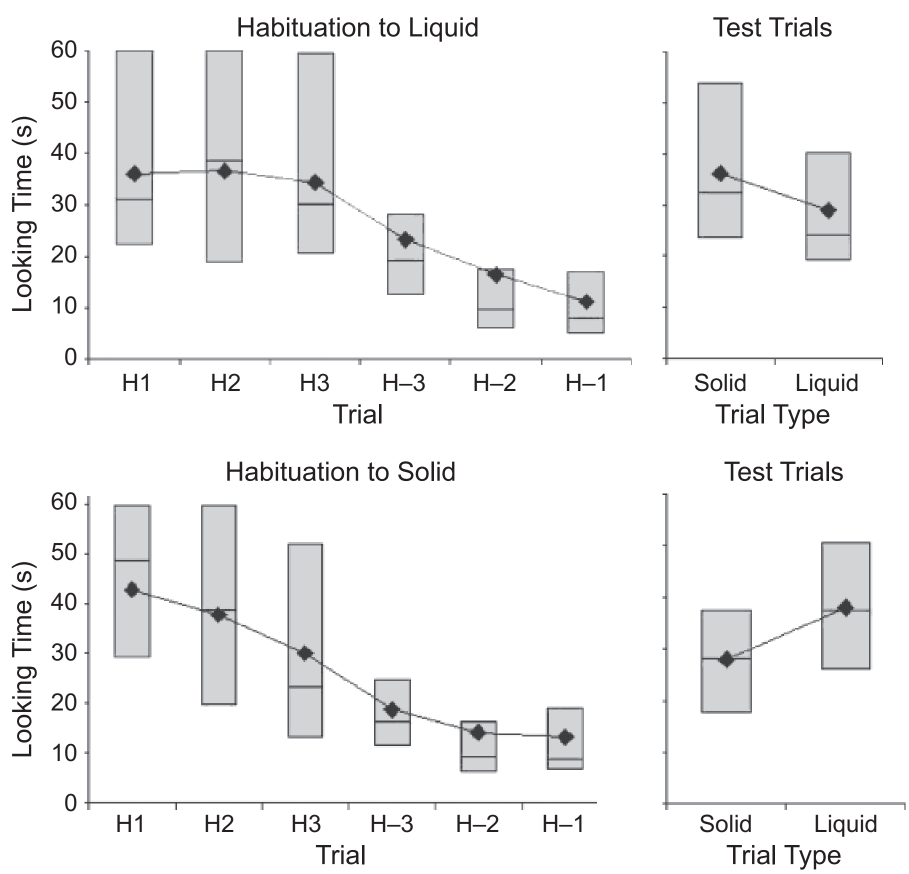

Fig. 2. Box plots showing mean looking times during the habituation and test trials in Experiment 1. Results for infants habituated to the liquid event are shown in the top row, and results for infants habituated to the solid event are shown in the bottom row. For habituation, the graphs include results for the first three trials (H1, H2, H3) and the last three trials before the habituation criterion was met (H−3, H−2, H−1). Black diamonds represent means, the central line in each box is the median, and the upper and lower portions of each box represent the third and the first quartiles, respectively.

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familiar events. A repeated measures analysis of variance (ANOVA) with factors of condition (habituation to liquid vs. habituation to solid) and test type (solid test trials vs. liquid test trials) revealed a significant interaction, $F(1, 30) = 13.52$, $p_{\mathrm{rep}} = .99$, $d = 0.99$, $\eta^2 = .31$.

The results were consistent within the two conditions as well. In the habituation-to-liquid condition, 13 out of 16 infants looked longer at the solid than at the liquid test trials ($p_{\mathrm{rep}} = .93$), and an ANOVA showed a main effect of test type, $F(1, 15) = 4.96$, $p_{\mathrm{rep}} = .89$, $d = 0.81$, $\eta^2 = .25$. In the habituation-to-solid condition, 13 out of 16 infants looked longer at the liquid than at the solid test trials, and an ANOVA again showed a main effect of test type, $F(1, 15) = 8.77$, $p_{\mathrm{rep}} = .95$, $d = 1.08$, $\eta^2 = .37$. There was no difference in looking times for solids versus liquids during habituation trials, $F(1, 30) < 1$. Similarly, there was no difference in looking times between solid and liquid test trials when these trials were both novel, $F(1, 15) < 1$, or when these trials were both familiar, $F(1, 15) < 1$. These findings provide evidence that the infants had different expectations for the liquid than for the solid events.

Discussion

Five-month-old infants use movement cues to discriminate a nonsolid substance from an object of similar appearance. Movement or lack of movement of the item relative to its container was diagnostic for participants in this experiment and allowed them to predict how the items would behave in later situations.

It is also possible that the shorter looking times for the familiar test events were due to the perceived similarity between the rotating motion of the liquid in the habituation trials and its pouring motion in the test trials. However, the looking-time difference between novel and familiar test trials was about the same in the liquid as in the solid condition. To explain this symmetry in the test results, the similarity hypothesis would have to include the provision that the motions of the solid were also similar in the habituation and test events. But it is difficult to suppose that the solid's fixed position in the glass during habituation had much in common perceptually with its tumbling between glasses in the test. Nevertheless, we thought it was worthwhile to consider a case in which the habituation and test trials would have no motion cues in common, so we explored such a case in Experiment 2.

EXPERIMENT 2

To address the issue of perceptual similarity between habituation and test events, and to investigate an additional aspect of infants' knowledge of liquids, we tested whether the effects observed in Experiment 1 would generalize to another physical attribute that distinguishes many nonsolid entities from solid ones, namely, penetrability. Solid objects tend to be impenetrable, whereas nonsolid substances, like water, tend to be penetrable. Hence, if infants recognize something as a solid, they should think it unlikely that another object will pass through it effortlessly. If infants recognize a substance as a liquid, however, they should expect penetration to be possible.

To test this hypothesis, we used the same habituation trials as in Experiment 1. These trials establish whether a glass contains a liquid or a solid object. In the test trials, we showed the infants a cylindrical pipe that was lowered either into the liquid or onto the top surface of the object. We expected that infants who were habituated to the object would find it novel for the pipe to proceed into the liquid. In contrast, we expected that infants who were habituated to the liquid would find it novel for the pipe to rest on top of the object. Such a pattern of results could not be due to similarity of motion, as neither the liquid nor the object moved during the test trials.

Method

Participants

The participants were 30 healthy, full-term infants (13 male and 17 female), ranging in age from 4 months 14 days to 5 months 12 days (M = 4 months 26 days). Half the infants were in the liquid condition; the other half were in the solid condition. Two additional infants were tested but eliminated from the final analyses, 1 because of fussiness and 1 because he looked the maximum amount on all test trials. The recruitment methods and demographics of the subject population were identical to those in Experiment 1.

Apparatus, Stimuli, and Events

The apparatus and stimuli were identical to those in Experiment 1, with the addition of a copper pipe (1 cm in diameter, 15 cm long) that was covered with black-and-white checkered paper.

The habituation trials were the same as in Experiment 1, except that the experimenter's other hand held the top of the checkered pipe in a vertical orientation, with the bottom of the pipe resting on the stage floor (see Fig. 3).

All participants saw two types of test trials in alternation (see Fig. 3). When the screen went up, one hand held the glass, and the other held the checkered pipe. The experimenter raised the pipe vertically (1 s), moved it horizontally until it was over the glass (1 s), and then slowly lowered the pipe inside the glass until it came in contact with the top surface of the solid (solid trials) or reached the bottom of the glass and paused (liquid trials; 3 s). Then the motions were reversed: The pipe was lifted vertically until it was above the glass (2 s), moved horizontally until it was over the initial position (1 s), and lowered until its bottom rested on the stage floor (1 s), where it remained for a pause (1 s). The 10-s cycle was repeated continuously until the trial ended. The only difference between the solid and liquid test trials was the difference in the contents of the glass, which determined whether the pipe came to rest on the top surface of the solid or the bottom of the glass (partially submerged in the liquid).

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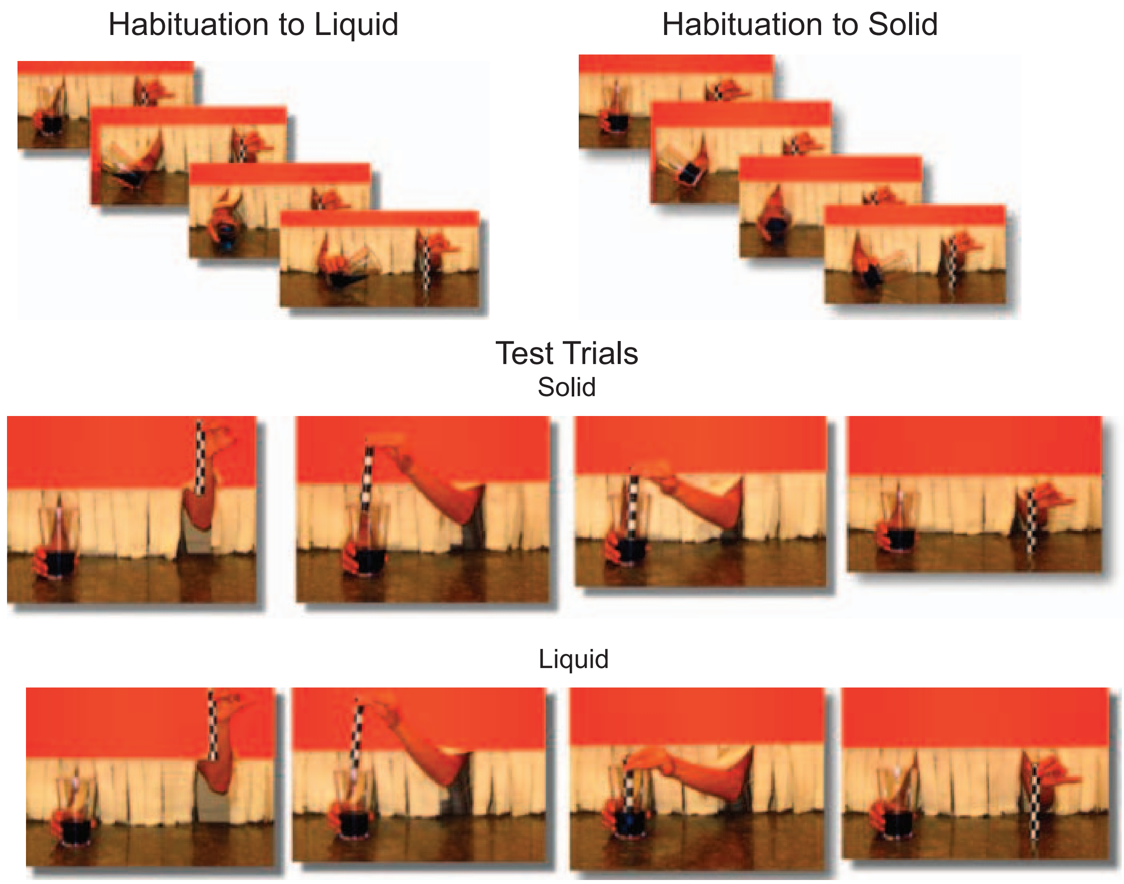

Fig. 3. Schematic illustration of the habituation and test trials in Experiment 2. Each infant saw either the solid or the liquid event during habituation. All infants received both the liquid and the solid test trials, presented in alternation. See the text for details.

Procedure

The procedure was identical to that in Experiment 1. The average number of trials to reach criterion was seven. Interobserver agreement in looking times was calculated for all infants and averaged 94%.

Preliminary analyses revealed no significant effect of sex or test-trial order on the infants' looking times. We therefore collapsed across these variables in subsequent analyses.

Results

Figure 4 presents the mean looking times on the habituation and test trials. For each infant, we calculated mean looking time for novel test events and for familiar test events. Twenty-six of the 30 infants looked longer at the novel test event than at the familiar test event ($p_{rep} = .99$, binomial comparison). Across all participants, the average looking times were 29.13 s ($SD = 15.1$) for the novel events and 23.31 s ($SD = 12.9$) for the familiar events. An ANOVA with the factors of condition (habituation to liquid vs. habituation to solid) and test type (solid test trials vs. liquid test trials) revealed a significant interaction, $F(1, 28) = 12.94$, $p_{rep} = .99$, $d = 0.96$, $\eta^2 = .32$.

The results were consistent within the two conditions as well. In the habituation-to-liquid condition, 12 out of 15 infants looked longer at the solid than at the liquid test trials ($p_{rep} = .93$), and an ANOVA showed a main effect of test event, $F(1, 14) = 4.60$, $p_{rep} = .88$, $d = 0.81$, $\eta^2 = .25$. In the habituation-to-solid condition, 12 out of 15 infants looked longer at the liquid than at the solid test trials ($p_{rep} = .93$), and an ANOVA again showed a main effect of test event, $F(1, 14) = 8.58$, $p_{rep} = .95$, $d = 1.11$, $\eta^2 = .38$. There was no overall difference in looking times for liquid versus solid habituation events, $F(1, 28) < 1$. We also found no reliable difference in looking times between liquid and solid test events when they were both novel, $F(1, 14) < 1$, or when they were both familiar, $F(1, 14) < 1$. The infants appeared to have different expectations for the liquid than for the solid events, but no baseline preference for one or the other.

Finally, an overall ANOVA with event (novel or familiar) as a within-subjects variable and habituation condition (liquid or solid) and experiment (1 or 2) as between-subjects variables revealed a main effect of event, $F(1, 58) = 25.02$, $p_{rep} = .99$, $d = 0.91$, $\eta^2 = .30$. No other main effects or interactions were significant.

Discussion

Five-month-old infants were able to predict the penetrability of an object or liquid from motion cues. Infants who saw the contents of the glass move (relative to the glass) during habituation

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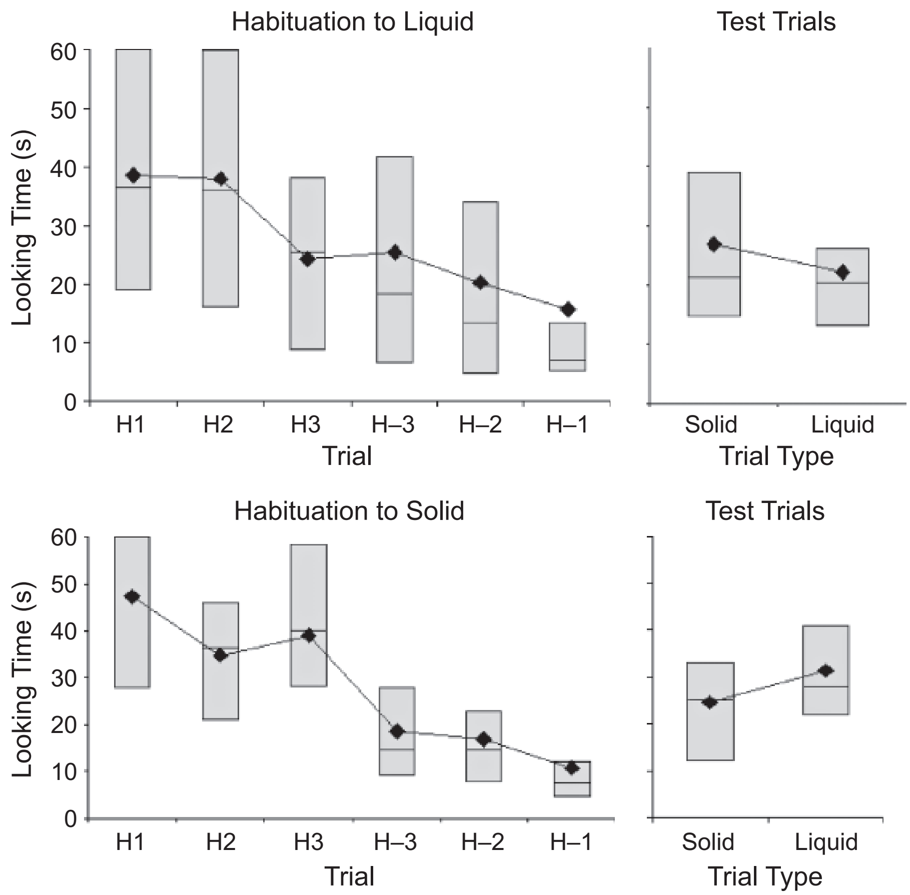

Fig. 4. Box plots showing the mean looking times during the habituation and test trials in Experiment 2. Results for infants habituated to the liquid event are shown in the top row, and results for infants habituated to the solid event are shown in the bottom row. For habituation, the graphs include results for the first three trials (H1, H2, H3) and the last three trials before the habituation criterion was met (H−3, H−2, H−1). Black diamonds represent means, the central line in each box is the median, and the upper and lower portions of each box represent the third and the first quartiles, respectively.

trials expected to see the pipe submerged in the liquid during test trials. Infants who saw the contents remain stationary during habituation trials expected the pipe to rest on top of the solid. As in Experiment 1, infants showed opposite patterns of looking to the same displays depending on what they saw during habituation trials.

As we noted earlier, an alternative account of the results from Experiment 1 explains the novelty reactions in terms of the perceptual similarity of the motions during habituation and test. However, perceptual similarity cannot account for the findings from Experiment 2 because both the object and the nonsolid substance were stationary during the test trials. Thus, the cues viewed in the habituation trials led to expectations more abstract than perceptual similarity, allowing the infants to predict penetrability of the contents of the glass.

The novel events in the test trials were not necessarily impossible ones. For example, the pipe could have stopped its trajectory at the top surface of a liquid if the experimenter had held the pipe in place. Nevertheless, infants who had been habituated to the liquid looked longer during test trials when the pipe stopped at the top surface of the cup's contents than when it continued to the bottom. Further research will need to specify the source of this reaction. We propose that infants' knowledge about solids and liquids is based on infants' experience outside the lab, and it is relatively rare for a solid (in this case, the pipe) to come to rest precisely at a liquid's surface.

GENERAL DISCUSSION

Infants are capable of noticing the characteristic difference between the movements of liquids and solids, and they can use this difference to predict later properties of these entities. These results imply that infants are quite capable of encoding and remembering liquids in ordinary contexts: Infants notice the motion of liquids in containers and the interaction between a liquid and a solid that penetrates its surface. Because the 5-month-olds in our experiments were many months from mastering the count/mass syntax of their native language, linguistic influences are unlikely to have been responsible for their successful

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performance. Instead, the capacity they demonstrated seems to be linked to mechanisms for representing physical entities and their motions, an ability potentially shared by other animals. Research on adults and children who are old enough to produce language has demonstrated that language experience influences the prominence of the count/mass distinction (Imai & Mazuka, 2007; Soja et al., 1991). These findings, along with those of Hespos and Spelke (2004), provide evidence that the early development of semantic categories parallels the development of phonological categories and suggest that natural-language semantics, like natural-language phonology, evolves so as to capitalize on preexisting representational capacities.

If 5-month-olds successfully distinguished solids and nonsolids in our displays, what accounts for their indifferent performance in earlier studies of their understanding of nonsolid substances? As we mentioned earlier, several factors may come into play. Some earlier experiments (e.g., Chiang & Wynn, 2000; Huntley-Fenner et al., 2002) focused on the ability to keep track of the number of substance piles, with spatial segregation imposing the grouping (e.g., discrete piles of sand or piles of blocks). Individuating substances in this way may pose special problems for infants, because the spatial boundaries and shapes of nonsolid substances tend to shift over time more radically than those of objects. Although the boundaries of the substances remained fixed in these earlier experiments, the infants may have ignored the boundary cues if such cues are typically unreliable in infants' ordinary experience. This explanation has the virtue of accounting for the fact that performance tends to be better when substances appear within containers, as in the study by Gao et al. (2000) and in the experiments we reported here.

But although boundary shifting may have been part of the reason for infants' failures in previous studies, the infants could have used other cues to succeed. For instance, they could have responded correctly simply by attending to the overall amount of nonsolid substances, as amount covaried with the number of groups. In Huntley-Fenner et al. (2002), for example, two piles of sand implied twice the amount of sand as one pile. Recent evidence suggests that infants register continuous amounts of substance in both solids (e.g., Clearfield & Mix, 2001; Feigenson, Carey, & Spelke, 2002) and nonsolids (Hespos, Dora, Rips, & Christie, 2008), at least in the case of small numbers of nondistinctive items (objects or piles). (However, see Cordes & Brannon, 2008, for difficulties infants have in cumulating amounts over several solid items.) Thus, it is unclear why infants failed in some earlier tasks in which total amount of stuff was an available and valid cue.

It is also difficult to explain all the results simply in terms of memory demands. Previous experiments required infants to remember the number of piles (or amounts) of a nonsolid substance while they were out of sight. Remembering items in a display is no doubt more difficult when infants view the display just once, as in the previous hidden-item tasks (Chiang & Wynn, 2000; Gao et al., 2000; Huntley-Fenner et al., 2002), than when they see a display repeatedly, as in the habituation paradigm we used. However, some hidden-items tasks have led to correct performance (e.g., Gao et al., 2000), whereas others have not (e.g., Huntley-Fenner et al., 2002), despite seemingly similar memory requirements. We conclude that some combination of factors may have disrupted infants' performance in earlier studies.

Whatever the reasons for the infants' difficulties in previous studies, the present results show that infants understand the properties of a liquid well enough to look longer when a subsequent display shows the liquid behaving in a way that mismatches its usual tendencies. We took as our starting point one type of object (a bounded, solid one) and one particular kind of substance (liquid). We did this because a solid object and a liquid are the clearest examples of their kinds. It is an open question, though, how far infants' knowledge extends. Liquids have properties that differ in some respects from those of other nonsolid substances, and liquids vary among themselves in properties such as viscosity. It is unclear whether infants discern subcategories among nonsolid substances or treat them all of a piece. And although infants appear to be sensitive to motion cues in liquids, it remains to be seen how closely their intuitive ideas about substances match those of adults (e.g., Hayes, 1988). For example, do they understand the laws governing the flow of nonsolid substances, or how nonsolid substances interact with solid boundaries?

In summary, these data conclusively demonstrate that 5-month-old infants encode liquids and solids differently, and that they have further expectations that follow from this categorization. More broadly, these experiments begin to clarify the beginnings of naive physics at the point where infants recognize that different types of entities behave in systematically different ways. Future studies will investigate how this recognition depends on general learning processes, on knowledge of the internal structure of the relevant domains, and on the particular experiences infants receive within the domains.

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REFERENCES

Aguiar, A., & Baillargeon, R. (1999). 2.5-month-old infants' reasoning about when objects should and should not be occluded. *Cognitive Psychology*, *39*, 116–157.

Baillargeon, R. (1995). A model of physical reasoning in infancy. In C. Rovee-Collier, L.P. Lipsitt, & H. Hayne (Eds.), *Advances in infancy research* (Vol. 9, pp. 306–352). Westport, CT: Ablex.

Chiang, W.-C., & Wynn, K. (2000). Infants' tracking of objects and collections. *Cognition*, *77*, 169–195.

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Clearfield, M.W., & Mix, K.S. (2001). Amount versus number: Infants' use of area and contour length to discriminate small sets. *Journal of Cognition and Development*, *2*, 243–260.

Cordes, S., & Brannon, E.M. (2008). The difficulties of representing continuous extent in infancy: Using numbers is just easier. *Child Development*, *79*, 476–489.

Feigenson, L., Carey, S., & Spelke, E.S. (2002). Infants' discrimination of number vs. continuous extent. *Cognitive Psychology*, *44*, 33–66.

Gao, F., Levine, S.C., & Huttenlocher, J. (2000). What do infants know about continuous quantity? *Journal of Experimental Child Psychology*, *77*, 20–29.

Hayes, P.J. (1988). Naive physics I: Ontology for liquids. In A.M. Collins & E.E. Smith (Eds.), *Readings in cognitive science: A perspective from psychology and artificial intelligence* (pp. 251–269). San Mateo, CA: Morgan Kaufmann.

Hespos, S.J., & Baillargeon, R. (2001a). Infants' knowledge about occlusion and containment events: A surprising discrepancy. *Psychological Science*, *12*, 141–147.

Hespos, S.J., & Baillargeon, R. (2001b). Reasoning about containment events in very young infants. *Cognition*, *78*, 207–245.

Hespos, S.J., Dora, B., Rips, L.J., & Christie, S. (2008). *Infants make quantity discriminations for substances*. Manuscript submitted for publication.

Hespos, S.J., & Spelke, E.S. (2004). Conceptual precursors to language. *Nature*, *430*, 453–456.

Huntley-Fenner, G., Carey, S., & Solimando, A. (2002). Objects are individuals but stuff doesn't count: Perceived rigidity and cohesiveness influence infants' representations of small groups of discrete entities. *Cognition*, *85*, 203–221.

Imai, M., & Mazuka, R. (2007). Language-relative construal of individuation constrained by universal ontology: Revisiting language universals and linguistic relativity. *Cognitive Science*, *31*, 385–413.

Kahneman, D., Treisman, A., & Gibbs, B.J. (1992). The reviewing of object files: Object-specific integration of information. *Cognitive Psychology*, *24*, 175–219.

Needham, A., & Baillargeon, R. (1993). Intuitions about support in 4.5-month-old infants. *Cognition*, *47*, 121–148.

Pinto, J.P. (1996). Xhab: Experimental control software for MS-DOS (Version 6.5) [Computer software]. Palo Alto, CA: Author.

Pylyshyn, Z. (2001). Visual indexes, preconceptual objects, and situated vision. *Cognition*, *80*, 127–158.

Soja, N.N., Carey, S., & Spelke, E.S. (1991). Ontological categories guide young children's inductions of word meaning: Object terms and substance terms. *Cognition*, *38*, 179–211.

Spelke, E.S. (1990). Principles of object perception. *Cognitive Science*, *14*, 29–56.

vanMarle, K. (2004). *Infants' understanding of number: The relationship between discrete and continuous quantity*. Unpublished doctoral dissertation, Yale University, New Haven, CT.

Wang, S.H., Baillargeon, R., & Paterson, S. (2005). Detecting continuity violations in infancy: A new account and new evidence from covering and tube events. *Cognition*, *95*, 129–173.

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