Cognition 175 (2018) 1–10

Contents lists available at ScienceDirect

Cognition

journal homepage: www.elsevier.com/locate/cognit

Original Articles

Five-month-old infants have expectations for the accumulation of nonsolid substances

Erin M. Anderson*, Susan J. Hespos, Lance J. Rips

Psychology Department, Northwestern University, United States

ARTICLE INFO

Keywords:
Cognitive development
Infant cognition
Substance concepts
Representation of nonsolids

ABSTRACT

Infants fail to represent quantities of non-cohesive substances in paradigms where they succeed with solid objects. Some investigators have interpreted these results as evidence that infants do not yet have representations for substances. More recent research, however, shows that 5-month-old infants expect objects and substances to behave and interact in different ways. In the present experiments, we test whether infants have expectations for substances when the outcomes are not simply the opposite of those for objects. In Experiment 1, we find that 5-month-old infants expect that when a cup of sand pours behind a screen, it will accumulate in just one pile rather than two. Similarly, infants expect that when two cups of sand pour in separate streams, two distinct piles will accumulate rather than one. Infants look significantly longer at outcomes with an inconsistent number of piles, providing evidence that infants have expectations for how sand accumulates. To test whether the number of cups or the number of pours guided expectations about accumulation, Experiment 2 placed these cues in conflict. This resulted in chance performance, suggesting that, for infants to build expectations about these outcomes, they need both cues (cup and pour) to converge. These findings offer insight into the nature of infants' representations for non-cohesive substances like sand.

1. Introduction: Knowledge of substances and its source

Our theories of how infants conceive entities in their environment have changed dramatically. Early theories suggested that infants perceive a sensory flux, aware of features like color and shape but not of individual objects (James, 1890). Subsequent evidence countered this view, showing that infants—even in the first weeks of life—have sophisticated knowledge about how objects behave and interact (Spelke, Breinlinger, Macomber, & Jacobson, 1992). Two-month-old infants have expectations about the naïve physics of occlusion and containment, and they look significantly longer at events that violate these expectations than at events that conform to them (Aguiar & Baillargeon, 1999; Baillargeon et al., 2012; Hespos & Baillargeon, 2001). These studies provide evidence that infants possess core principles about the solidity, continuity, and persistence of objects.

Although studies of early object concepts demonstrated that infants perceive objects in much the way adults do, the world is not made of objects alone. Nonsolid substances like water, milk, and soil are intrinsic parts of human experience, and our interactions with these substances differ markedly from our interactions with objects. We expect to be able to push a toy car across the floor but not a puddle of water. Our reactions in these situations reflect our awareness that objects and substances have distinct physical properties and so behave in distinct but predictable ways. However, current evidence about infants' knowledge of substances is less detailed than evidence about their knowledge of objects. Do infants have substance-specific expectations? Or, do beliefs about objects arise from a privileged domain of knowledge, while our beliefs about substances derive from how they differ from objects?

Current evidence is unclear on whether infants have principled expectations for non-cohesive substances, with early results suggesting gaps in their knowledge (Cheries, Mitroff, Wynn, & Scholl, 2008; Chiang & Wynn, 2000; Huntley-Fenner, Carey, & Solimando, 2002; Rosenberg & Carey, 2009). Huntley-Fenner et al. (2002) showed 8-month-old infants a pile of sand, then concealed the pile behind a screen, and, 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. But with similar-looking (but solid) sand-pile shaped objects, infants performed as expected in this paradigm, looking longer at the one-object display than at the two-object display. Together, these findings suggest that infants may have so little knowledge of (or so little ability to

* Corresponding author at: Department of Psychology, Northwestern University, 2029 Sheridan Road, Evanston, IL 60208, United States.
E-mail address: erinanderson2014@northwestern.edu (E.M. Anderson).

https://doi.org/10.1016/j.cognition.2018.02.009
Received 29 March 2016; Received in revised form 5 February 2018; Accepted 8 February 2018

process) substances that they are unable to predict a substance's continued presence when it is briefly out of sight. Spelke and Kinzler (2007) took this interpretation a step further: They proposed that infants have principled expectations for objects but not for substances.

Infants' difficulties with non-cohesive substances extend to collections of small solid objects. In a paradigm similar to Huntley-Fenner et al. (2002), Chiang and Wynn (2000) showed 8-month-old infants a noncohesive pile of Lego pieces or a cohesive Lego pyramid. In the noncohesive case, after concealing a first pile behind a screen, the experimenter brought out a second pile of Legos and placed it behind a separate screen. When the screens were removed, only one pile of Legos appeared. Looking time at this magical disappearance was compared to a second condition consisting of an expected disappearance from two piles on the stage. In this second condition, after screens concealed both piles, infants then saw one pile removed from behind a screen. When the screens were removed, only one pile remained. The infants spent no more time looking at the magical disappearance than at the expected disappearance when noncohesive piles of Legos were used. However, when the Legos were pressed together to form cohesive pyramids and were lowered behind the screens, infants performed as expected, looking significantly longer at the 2–0 = 1 display than at the 2–1 = 1 display. Chiang and Wynn (2000) concluded that infants track cohesive objects as discrete individuals but cannot track non-cohesive entities.

In contrast to these findings, more recent studies suggest that basic reasoning about non-cohesive substances appears in the first months of life, provided infants are tested on principles appropriate to them. Hespos, Ferry, and Rips (2009) found that infants are sensitive to motion cues for a liquid and that these cues then guide their expectations about how the liquid will behave. In the habituation trials, infants viewed a clear cup containing a liquid whose surface deformed and shifted as liquids ordinarily do when the cup was tilted and rotated. This cue led them to look longer when the cup was upturned and the contents tumbled out (as if solid) compared with when the cup was upturned and the contents poured out (as if liquid). In a second experiment, infants who saw the same motion cues in the tilting cup expected that the contents were permeable—for example, that a solid cylinder would pass through the top surface and not remain on top. It is possible that infants' expectations are specific to liquids, emerging from their early experience drinking and bathing. Yet new research reveals that expectations about the non-cohesive qualities of liquids generalize to other substances (Hespos, Ferry, Anderson, Hollenbeck, & Rips, 2016). When infants viewed a clear cup containing sand that was tilted and rotated, the motion cues caused them to expect that the contents would pass through a grid. In addition, when the contents of the clear cup were tiny glass balls that tilted back and forth in the cup, infants expected that a solid object would pass through the top surface and not remain on top. In each of these experiments, an object condition showed that the converse was true, too: Infants looked longer at substance behaviors when they expected an object and at object behaviors when they expected a substance. Together, these findings provide evidence that principles for non-cohesive substances emerge around the same time as object principles in development and apply to unfamiliar as well as to familiar materials.

The evidence from these paradigms successfully counters the claim that infants cannot represent non-cohesive substances. However, these studies leave unclear the source of infants' substance knowledge. On the one hand, infants may gain this knowledge directly from the substances themselves, mastering principles that are specific to substances (see Rips & Hespos, 2015, for a discussion of these principles). On the other hand, their substance knowledge may arise in a derivative way from simple contrasts with object knowledge. According to the latter alternative, they may identify substances as non-objects and predict the substances' behavior as the opposite of objects'. If this is true, expectations for substances might still be built on the expectations for objects that appear in the first three months of life (Spelke et al., 1992). Past studies of substances like Hespos et al. (2009) cannot resolve this issue because test trials in these experiments always contrasted object and substance outcomes: If a solid stops another solid at its surface, a substance should allow the solid to go through. If a solid maintains its shape, a substance should deform. If a solid cannot pass through a small grid, a substance should.

In the current study, we wanted to test infant expectations for non-cohesive substances when the probable outcome was not simply the opposite of an object outcome. To do this, we looked at pouring sand into piles. Non-cohesive substances like sand can merge into a single pile or divide into separate piles, depending, in principled ways, on the situation. For example, consider sand poured from a cup onto a table. Pouring the sand can create a specific number of piles, depending on the location of the pours. Two pours in distinct locations normally produce two piles, whereas two pours in the same location normally produce one. Solid objects, on the other hand, do not merge or divide under the same conditions. Dropping solid objects does not typically change the number of objects in a way that depends lawfully on location (e.g., dropping two apples in one vs. two locations does not change the number of apples). For this reason, an infant who knows only (a) the behavior of solid objects under these transformations and (b) that nonsolids behave in ways opposite that of solids, would not be able to predict how the number of piles of nonsolids varies with the location of pours. If, however, they are able to reason about the sand's behavior independent of object rules, then they should expect that the number of piles will match the number of pours into distinct locations.

2. Experiment 1: Do infants know that the number of pours determines the number of piles?

In the current study, we test infants' expectations about the naïve physics of sand. If infants see a single cup of sand poured behind a screen, would it violate their expectations to reveal two distinct piles?

2.1. Method

We tested whether 5-month-old infants have principled beliefs about the non-cohesive nature of sand during pouring events. Infants were randomly assigned to either the single-pour or double-pour condition. Fig. 1 illustrates these events. In the single-pour habituation condition, infants saw a single cup filled with sand poured onto a tray. A screen hid the portion of the tray where the sand accumulated. In the double-pour habituation condition, infants saw simultaneous pours from two cups of sand emptied in separate streams onto a tray. Again, a screen hid the portion of the tray where the sand accumulated. After each pour, the tray was removed from the stage and emptied. The pouring/emptying cycle was repeated continuously until the trial ended. After habituation trials were over, the infants saw an alternation between two types of test trials. The only difference between habituation and test events was that the screen was removed after each pour, revealing sand piles on the tray. When the screen was removed, on half the trials it revealed a single pile of sand, and on alternate test trials, two separate piles. If infants have expectations about sand that go beyond a mere contrast with object rules, then infants in the single-pour condition should look longer at the two-pile test trials compared to the one-pile test trials. For infants in the double-pour condition, we would expect the opposite pattern of results.

2.1.1. Participants

The participants were 34 healthy, full-term infants (16 female, 18 male), ranging in age from 4 months 15 days to 6 months 16 days (M = 5 months 12 days). Half the infants were assigned to the single-pour condition (M = 5 months 13 days, 9 female) and the other half were assigned to the double-pour condition (M = 5 months 10 days, 7 female). Eleven additional infants were tested but eliminated from the final analysis: one because of fussiness (defined as more than four test trials in which the infant was coded as crying or fussy by two