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Brief article

Young infants view physically possible support events as unexpected: New evidence for rule learning

Su-hua Wang[a,*], Yu Zhang[a], Renée Baillargeon[b]

[a] University of California, Santa Cruz, United States
[b] University of Illinois at Urbana-Champaign, United States

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ABSTRACT

It has been suggested that one of the mechanisms by which infants acquire their physical knowledge is rule learning: Infants generate rules about the likely outcomes of events and revise these rules when confronted with discrepant outcomes. This approach predicts that when infants' rules are only partially correct, they will view as unexpected events that are physically possible and even ordinary but happen to contradict their faulty rules. Here we provide evidence for this prediction in young infants' responses to support events. According to prior findings, by 6.5 months of age, most infants expect an object to be stable if released with half or more of its bottom surface on a support; by 8 months, most infants have refined this rule and realize that an object can be stable with less support as long as the middle of the object's bottom surface is supported. In line with these findings, 7.5- but not 8.5-month-olds viewed as unexpected a possible event in which a wide box remained stable when released with only the middle third of its bottom surface resting on a narrow platform. These results provide new evidence that young infants, like older children and adults, generate and revise rules to make sense of physical events.

1. Introduction

How do infants acquire their physical knowledge? According to several researchers (e.g., Baillargeon & DeJong, 2016; Gopnik, 2012; Gopnik, Griffiths, & Lucas, 2015; Leslie, 2004; Perfors, Tenenbaum, Griffiths, & Xu, 2011; Wang & Baillargeon, 2008a), one important mechanism is rule learning: Infants generate abstract rules about the likely outcomes of events (via explanation-based and statistical learning processes), and they revise these rules when events do not unfold as expected, so as to better predict outcomes in the future.

As with older children and adults (e.g., Andrews, Halford, Murphy, & Knox, 2009; Kaiser, McCloskey, & Proffitt, 1986; Karmiloff-Smith & Inhelder, 1975; Krist, 2010; Legare, 2012; Siegler & Chen, 1998), robust evidence of rule learning in infants comes from the systematic errors they produce when their rules are only partially correct. Of particular interest are *errors of commission*, where infants view as unexpected events that are physically possible and even ordinary but happen to be inconsistent with their faulty rules. These errors contrast with *errors of omission*, where infants view as expected events that are physically impossible but happen to be consistent with their faulty rules. Unlike errors of omission, which amount to failures to detect violations and can be explained by various developmental mechanisms, errors of commission involve perceiving violations where there are none and, as such, are most easily explained by a rule-learning mechanism.

Although there have been numerous reports of errors of omission in infants' responses to impossible events (e.g., Hespos & Baillargeon, 2001; Wang, Baillargeon, & Paterson, 2005; Wilcox, 1999; Xu & Carey, 1996), to date there has been only one report of errors of commission, in 3-month-olds' responses to possible occlusion events (Luo & Baillargeon, 2005). The present research sought new evidence of errors of commission, in 7.5-month-olds' responses to support events. We reasoned that positive results would demonstrate that errors of commission occur at different ages and with different events, supporting the claim that rule learning is part of infants' fundamental approach to making sense of the physical world.

1.1. Errors of commission

Under what conditions do infants view physically possible events as unexpected? The account of infants' physical reasoning we have been developing suggests an answer to this question (Baillargeon, Li, Gertner, & Wu, 2011; Baillargeon, Li, Ng, & Yuan,

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[*] Corresponding author at: University of California, 1156 High Street, Santa Cruz, CA 95064, United States.

E-mail address: suhua@ucsc.edu (S.-h. Wang).

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2009; Wang & Baillargeon, 2008b). Below, we summarize our account in terms of two main findings and then explain how it helps predict infants' errors of commission.

First, beginning early in life, infants form distinct event categories, such as occlusion, support, and collision events (e.g., Leslie & Keeble, 1987; Rigney & Wang, 2015; Wang & Baillargeon, 2006). An event category represents a type of causal interaction in which objects serve distinct event roles (e.g., occluder, occludee). Each category has a number of vectors, which correspond to different facets of the events and represent separate problems that must be solved to accurately predict how the events will unfold. For example, when an occludee moves behind an occluder, infants must learn to predict whether the occludee will remain fully and continuously hidden behind the occluder, where and when the occludee will reappear from behind the occluder, and whether the occludee that reappears is the same occludee that disappeared or a different occludee (e.g., Kochukhova & Gredebäck, 2007; Wang, Baillargeon, & Brueckner, 2004; Wilcox, 1999).

Second, in each vector, infants identify a rule for predicting outcomes; this rule calls attention to a feature of the events and specifies how to interpret this information (e.g., Kotovsky & Baillargeon, 1998; Wang, Kaufman, & Baillargeon, 2003; Wang & Kohne, 2007). With experience, infants may notice that while some outcomes support the rule, others contradict it. When this occurs, a new rule is added to the vector, and this revision process is repeated as needed, allowing infants to predict outcomes in the vector more and more accurately over time (Baillargeon & DeJong, 2016). To illustrate, 3-month-olds typically use a *lower-edge-continuity* rule to predict whether occludees will be hidden: If an occludee passes behind an occluder whose lower edge is not continuous with the surface on which it rests, creating an opening between the occluder and the surface, infants expect the occludee to appear in this opening; when no such opening exists, infants expect the occludee to remain hidden (Aguiar & Baillargeon, 1999, 2002). By about 3.5 months, most infants have added a new rule to the vector, *height*: They now expect an occludee to be visible, even when passing behind an occluder whose lower edge is continuous with the surface on which it rests, if this occludee is taller than any portion of the occluder (Baillargeon & DeVos, 1991; Hespos & Baillargeon, 2001, 2006).

The preceding account predicts that errors of commission will occur whenever infants have acquired only the initial rule(s) in a multi-rule vector and encounter events that violate their expectations. As Leslie (2004) stated, "A violation of expectation happens when you detect that the world does not conform to your representation of it. Bringing representation and world back into kilter requires representation change, and computing the right change is a fair definition of learning" (p. 418).

Existing evidence for infants' errors of commission comes from an experiment on 3-month-olds' responses to occlusion events (Luo & Baillargeon, 2005); as explained above, most infants this age have acquired the rule *lower-edge-continuity*, but not the rule *height*. Infants were first familiarized with a tall cylinder that moved back and forth behind a tall screen. Next, most of the screen's midsection was removed, creating a large opening; a short strip remained either below (*U-shape* event) or above (*inverted-U-shape* event) this opening. In both events, the cylinder became visible in the screen's opening. As predicted, infants looked reliably longer at the U-shape than at the inverted-U-shape event: Their partially correct rule *lower-edge-continuity* led them to commit an error of commission and view the physically possible U-shape event as unexpected.

1.2. Support events

According to our account, errors of commission will occur whenever infants have acquired some, but not all, of the rules in a multi-rule vector. To test this prediction, here we focused on a different event category, support events, and on older infants, 7.5-month-olds.

In everyday life, infants often observe and (beginning in the second half-year) produce simple support events in which an object is released on top of another object (henceforth *platform*). With experience, infants acquire a series of rules about whether the object

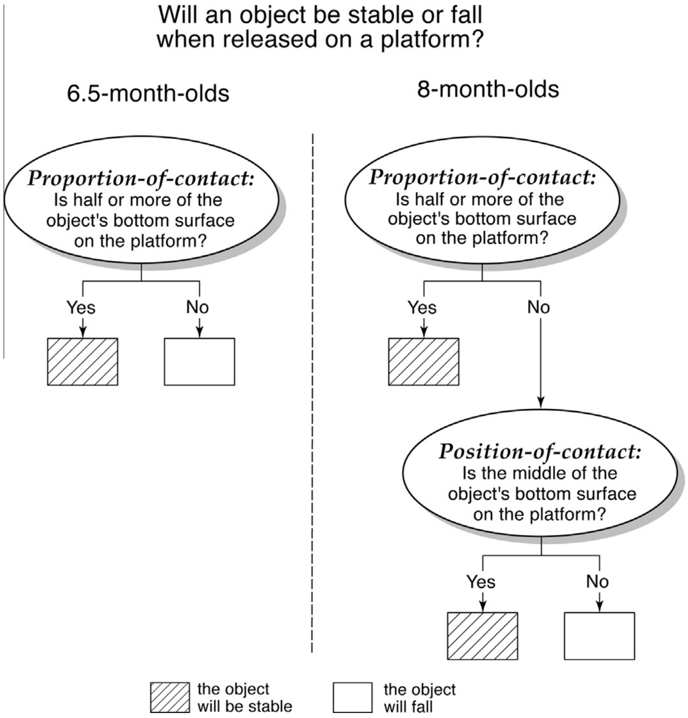

Fig. 1. Decision trees depicting some of the support rules infants use at 6.5 and 8 months of age to predict whether an object will remain stable or fall when released on a platform.

will remain stable or fall when released on the platform (see Fig. 1 for a portion of this multi-rule vector). By about 6.5 months, most infants have acquired a *proportion-of-contact* rule: They expect the object to remain stable if half or more of its bottom surface rests on the platform, and to fall otherwise (Baillargeon, Needham, & DeVos, 1992; Hespos & Baillargeon, 2008; Luo, Kaufman, & Baillargeon, 2009). By about 8 months, most infants have acquired an additional rule, *position-of-contact*: They recognize that an object can be stable with less support as long as it is the middle rather than the left or right side of the object's bottom surface that is supported (Dan, Omori, & Tomiyasu, 2000; Huettel & Needham, 2000).

These findings predicted that 7.5-month-olds would produce an error of commission and view as unexpected a physically possible support event in which an object remained stable with only the middle third of its bottom surface supported. Our research tested this prediction.

2. Experiment

Infants ages 7.5 and 8.5 months were randomly assigned to a middle-contact or a side-contact condition (Fig. 2). In both conditions, infants received a single test trial in which they saw either a wide-box or a narrow-box event. The events involved a platform (10 cm wide), a wide box (30 cm), and a narrow box (15 cm).

At the start of the *wide-box* event in the *middle-contact* condition, the platform rested on the floor of a puppet-stage apparatus, 17 cm from the right wall; the wide box stood 8 cm to the left of the platform, and the narrow box stood 8 cm to the left of the wide box. An experimenter's gloved hand tapped the top of the wide box until the infant had looked for 2 cumulative seconds. Next, the hand centered the wide box on top of the platform, released it, and paused above it for about 2 s (the box always remained stable when released); the hand then returned the box to its starting position. Each event cycle lasted about 13 s, and cycles were repeated until the trial ended (see Procedure). The *narrow-box* event was identical except that the boxes' positions were reversed and the narrow box was placed on the platform. In this condition, the middle 33% of the wide box, or the middle 67% of the narrow box, rested on the platform.

The *side-contact* condition was identical to the middle-contact condition except that the platform stood either 7 cm (wide-box event) or 14.5 cm (narrow-box event) from the right wall. Although in each event the hand placed the box in the same absolute position as before, the right edge of the box was now aligned with that of the platform. In the wide-box event, a hidden weight

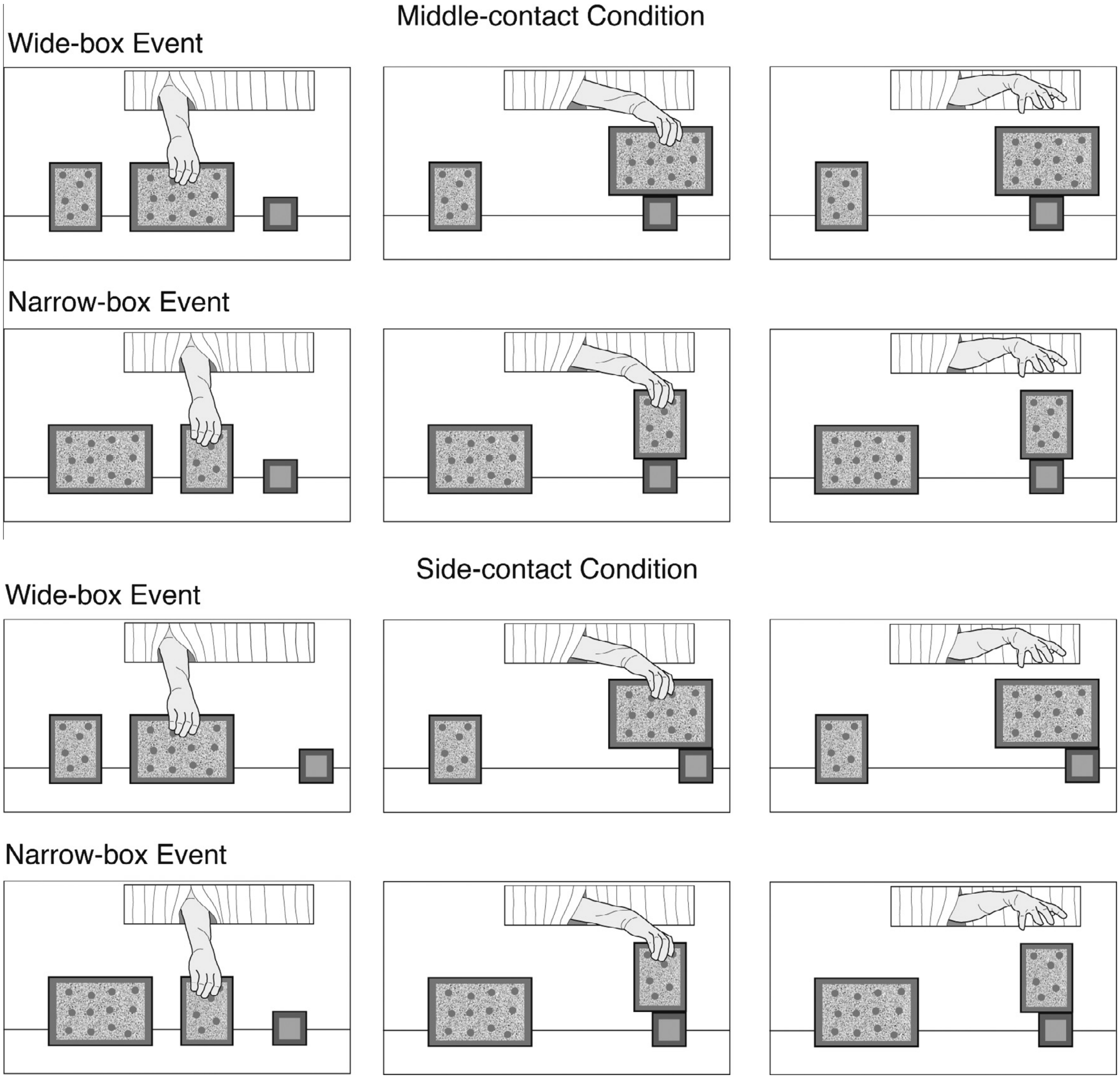

Fig. 2. Events shown in the middle-contact (top) and side-contact (bottom) conditions of the main experiment. Events in the control experiment were identical except that after placing the box on the platform, the hand simply paused while holding the box, without releasing it. Event cycles were repeated until the trial ended.

allowed the box to remain stable when released. In this condition, the right 33% of the wide box, or the right 67% of the narrow box, rested on the platform.

At 7.5 months of age, infants' *proportion-of-contact* rule should lead them (a) to view the wide box as inadequately supported in both the middle-contact and side-contact conditions (in each case, only 33% of the box's bottom surface lay on the platform) and (b) to view the narrow box as adequately supported in both conditions (in each case, 67% of the box's bottom surface lay on the platform). Infants in both conditions should thus look reliably longer if shown the wide-box as opposed to the narrow-box event.

At 8.5 months of age, infants' *proportion-of-contact* and *position-of-contact* rules should lead them to hold similar expectations with one exception: In the middle-contact condition, infants should view the wide box as adequately supported, because the middle third of its bottom surface lay on the platform. Infants in the side-contact condition should thus look reliably longer if shown the wide-box as opposed to the narrow-box event, whereas infants in the middle-contact condition should look equally at the two events.

Additional infants were tested in a *control experiment* identical to the main experiment except that the hand never released the box: After lowering the box onto the platform, the hand paused briefly and then lifted it again (each event cycle lasted about 11 s). Negative results in this experiment would rule out low-level alternative interpretations of positive results in the main experiment (e.g., infants simply preferred certain arrangements of the boxes and platform).

2.1. Method

2.1.1. Participants

Participants were 128 healthy term infants, 64 male; half were 7.5-month-olds (M = 7 months, 23 days, range = 7,16–8,0) and half were 8.5-month-olds (M = 8 months, 14 days, range = 8,3–8,29). Another 5 infants were excluded because they were distracted (2), fussy (2), or drowsy (1). At each age, 16 infants were assigned to each of the four groups formed by crossing the two experiments (main, control) and conditions (middle-contact, side-contact). Within each group, half the infants saw the wide-box event, and half saw the narrow-box event.

2.1.2. Apparatus

The apparatus consisted of a brightly lit display booth (128 cm high × 101 cm wide × 51 cm deep) with a large opening (43 × 94) in its front wall; before the trial, a supervisor raised the curtain (61 × 100) that hid this opening. Inside the apparatus, the walls were white, and the floor was covered with pastel adhesive paper. The experimenter introduced her right hand (in a yellow glove) into the apparatus through a window (12 × 56, filled with white fringe) in the back wall. The platform (10 × 10 × 15) was covered with green adhesive paper, and it edges were lined with green tape. The wide (20 × 30 × 10) and narrow (20 × 15 × 10) boxes were covered with gray granite-textured adhesive paper and decorated with red dots, and their edges were lined with red tape.

2.1.3. Procedure

Infants sat on a parent's lap in front of the apparatus; parents were instructed to remain silent and close their eyes. Before the session, infants were shown the experimenter's gloved hand, platform, and boxes. During the session, each infant's looking behavior was monitored by two hidden observers who were unaware of the experiment and condition to which the infant was assigned and of the event presented; looking times were computed using the primary observer's responses. The trial ended when infants (a) looked away for 1 consecutive second after having looked for at least 8 cumulative seconds or (b) looked for 60 cumulative seconds. The 8-s value ensured that infants in the main experiment had the opportunity to see that the boxes remained stable when released. Inter-observer agreement averaged 96.4% per infant. Preliminary analyses revealed no significant interactions of condition and event with infants' sex; the data were therefore collapsed across the latter factor in subsequent analyses.

2.2. Results

Infants' looking times in the *main* experiment (Fig. 3, Table 1) were compared by an ANOVA with age (7.5 or 8.5 months), condition (side- or middle-contact), and event (wide- or narrow-box) as between-subjects factors. The analysis yielded a significant main effect of event, $F(1,56) = 26.25$, $p < 0.0001$, a significant Condition × Event interaction, $F(1,56) = 5.18$, $p < 0.05$, and, critically, a significant Age × Condition × Event interaction, $F(1,56) = 7.13$, $p < 0.01$, $\eta_p^2 = 0.11$. As predicted, planned comparisons revealed that at 7.5 months, infants in both the side-contact condition, $F(1,56) = 9.73$, $p < 0.005$, Cohen's $d = 1.38$, and the middle-contact condition, $F(1,56) = 12.32$, $p < 0.001$, $d = 1.83$, looked reliably longer if shown the wide-box as opposed to the narrow-box event; at 8.5 months, infants in the side-contact condition again looked reliably longer if shown the wide-box as opposed to the narrow-box event, $F(1,56) = 18.33$, $p < 0.0001$, $d = 2.00$, but infants in the middle-contact condition looked equally at the two events, $F(1,56) < 1$. The two age groups differed reliably in their looking times at the wide-box event in the middle-contact condition, $F(1,56) = 7.96$, $p < 0.01$, $d = 1.43$, but not the side-contact condition, $F(1,56) = 1.16$, $p > 0.25$; there were no significant differences for the narrow-box event, both $Fs(1, 56) < 1.84$, $ps > 0.20$.

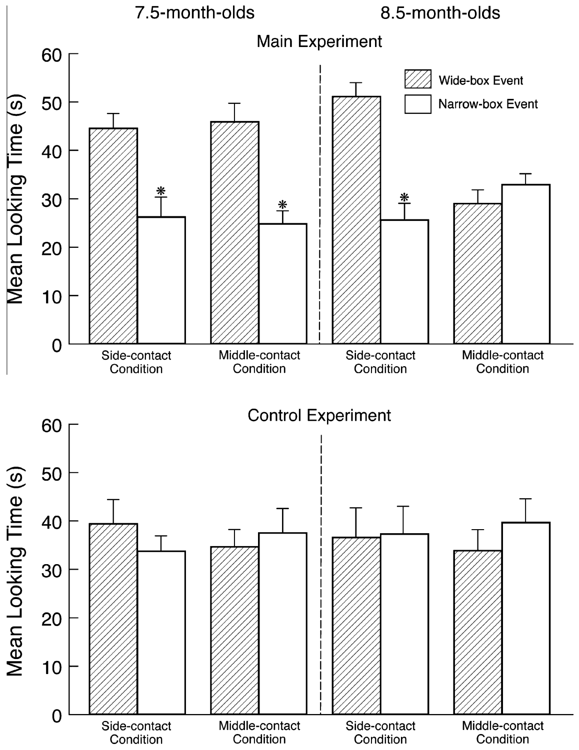

Fig. 3. Mean looking times at the wide-box and narrow-box events, separately per experiment, age group, and condition. Errors bars represent standard errors, and an asterisk denotes a significant difference between events ($p < 0.05$ or better). Nonparametric two-tailed Wilcoxon rank-sum tests confirmed the results of the main experiment (7.5-month-olds: side-contact $W = 48$, $p < 0.05$; middle-contact $W = 42$, $p < 0.01$; 8.5-month-olds: side-contact $W = 43$, $p < 0.025$; middle-contact $W = 76$, $p > 0.10$) and the control experiment (all $Ws > 54$, $ps > 0.10$).

Table 1
Mean looking times (in seconds) and standard deviations (in parentheses) at the wide-box and narrow-box events, separately per experiment, age group, and condition.

	7.5-month-olds		8.5-month-olds	
	Wide-box Event	Narrow-box Event	Wide-box Event	Narrow-box Event
Main experiment				
Side-contact Condition	44.4 (12.0)	25.9 (14.8)	50.8 (11.4)	25.3 (13.9)
Middle-contact Condition	45.5 (12.4)	24.6 (10.3)	28.7 (11.1)	32.6 (7.8)
Control experiment				
Side-contact Condition	39.7 (19.4)	34.0 (13.1)	36.8 (22.3)	37.4 (21.7)
Middle-contact Condition	34.7 (13.5)	37.7 (19.0)	33.9 (17.8)	39.8 (19.2)

Looking times in the *control* experiment (Fig. 3, Table 1) were analyzed as above and yielded no significant effects, all $Fs(1,56) < 1$.

A final ANOVA compared responses to the wide-box and narrow-box events in the three conditions of the main experiment with positive results (7.5-months/side-contact, 7.5-months/middle-contact, and 8.5-months/side-contact) to responses in the corresponding conditions of the control experiment. This analysis yielded a significant Experiment × Event interaction, $F(1,84) = 10.48$, $p < 0.0025$, $\eta_p^2 = 0.11$, confirming that responses in these three conditions differed reliably between the two experiments.

3. Discussion

According to our account of early physical reasoning, infants who have acquired only the initial rule(s) in a multi-rule vector will detect a violation when shown a physically possible event inconsistent with their partially correct rule(s). Our results provide new evidence for this prediction: 7.5-month-olds, whose knowledge of support typically includes the *proportion-of-contact* rule but not yet the *position-of-contact* rule, detected a violation when a wide box remained stable with only the middle third of its bottom surface supported; 8.5-month-olds, who typically know both of these rules, correctly viewed this event as expected. For infants as for adults, what is unexpected lies in the eye of the beholder.

Our results support three main conclusions. First, they reinforce the claim that an important mechanism in infants' acquisition of physical knowledge is rule learning. If early event representations simply mirrored the world, infants would be unlikely to ever view ordinary, possible events as unexpected. Infants' errors of commission demonstrate that they generate abstract rules that are often initially imperfect and must be revised to be in better alignment with the world.

Second, our findings support our account of early physical reasoning and in particular our claim that infants' acquisition of physical knowledge proceeds in a piecemeal and incremental manner, event category by event category, vector by vector, and rule by rule (for similar results with adults, see Strickland & Scholl, 2015).

Finally, our findings make clear that the violation-of-expectation method takes advantage of infants' natural tendency to explore events that are inconsistent with their expectations. Outside of developmental laboratories, infants rarely see physically impossible events, but they often see physically possible events that contradict their faulty rules; these violations "provide special opportunities for learning" (Schulz, 2015, p. 43). Recent findings by Stahl and Feigenson (2015) showed that 11-month-olds were more likely to explore and learn new information about objects from physically impossible events; future research can explore whether the same is true of objects from physically possible events that happen to violate infants' faulty rules.

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Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.cognition.2016.08.021.

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