Event categorization in infancy

Renée Baillargeon and Su-hua Wang

Recent research suggests that one of the mechanisms that contribute to infants' acquisition of their physical knowledge is the formation of event categories, such as occlusion and containment. Some of this research compared infants' identification of similar variables in different event categories. Marked developmental lags were found, suggesting that infants acquire event-specific rather than event-general expectations. Other research – on variable priming, perseveration, and object individuation – presented infants with successive events from the same or from different event categories. To understand the world as it unfolds, infants must not only represent each separate event, but also link successive events; this research begins to explore how infants respond to multiple events over time.

Over the past 15 years, a dramatic change has taken place in the field of infant cognition: researchers have come to realize that, contrary to traditional claims [1,2], infants possess sophisticated expectations about physical events [3–12]. Of main concern today is the issue of how infants acquire their physical knowledge. In particular, what specialized mechanisms contribute to this acquisition process [13–17]? In this article, we review evidence that one such mechanism involves the formation of *event categories*: infants appear to 'sort' physical events into distinct categories, and to learn and reason in terms of these categories.

The article is organized into two main sections. In the first, we summarize experiments that compared infants' knowledge of similar expectations in different event categories. This research has brought to light striking developmental lags (or décalages, to use a Piagetian term [18]) in infants' acquisition of their physical knowledge, with several months separating similar acquisitions across categories. In the second section of the article, we review experiments on variable priming, perseveration, and object individuation, all of which presented infants with successive events from the same or from different event categories. Depending on the task, the change in event category either improved or impaired infants' performance.

Learning about event categories

Research conducted during the 1990s revealed a clear overall pattern in the development of infants' physical knowledge (for reviews, see Refs [13,19–21]). When learning about occlusion, support, and other physical events, infants first form an initial concept centered on a primitive, all-or-none distinction. With further experience, infants identify discrete and continuous variables that elaborate this initial concept, resulting in increasingly accurate predictions over time.

One limitation of this research was that it left unclear how general or specific were infants' expectations. Because the events examined – such as occlusion and support – were physically very different, the variables identified for each event were naturally also very different. To ascertain whether infants acquire general or specific expectations about events, it was necessary to compare their knowledge of the same variable in different events. Evidence that infants considered a given variable when reasoning about all relevant events would suggest that their expectations were 'event-general'. On the other hand, evidence that infants took into account a given variable when reasoning about one but not other, equally relevant events, would suggest that their expectations were 'event-specific'.

To date, three series of experiments have compared infants' reasoning about similar variables in different events. All of these experiments used the violation-of-expectation method [21]. In a typical experiment conducted with this method, infants see two test events: one (expected event) is consistent with the expectation being examined in the experiment; the other (unexpected event) violates this expectation. With appropriate controls, evidence that infants look reliably longer at the unexpected than at the expected event indicates that they: (1) possess the expectation under examination; (2) detect the violation in the unexpected event; and (3) are interested or surprised by this violation.

Height in occlusion and containment events

In a recent experiment, Hespos and Baillargeon [22] compared 4.5-month-old infants' ability to reason about the variable height in occlusion and in containment events. The infants watched test events in which an object was lowered either behind an occluder (occlusion condition; Fig. 1a) or inside a container (containment condition; Fig. 1b). The object consisted of a tall cylinder with a knob affixed to its top; in all of the events, the object was lowered until only the knob remained visible. In the expected events, the occluder or container was as tall as the cylindrical portion of the object; in the unexpected events, the occluder or container was only half as tall, so that it should have been impossible for the cylindrical portion of the object to become fully hidden (see Fig. 1). The tall and short occluders were identical to the tall and short containers with their back halves and bottoms removed.

The infants in the occlusion condition looked reliably longer at the unexpected than at the expected event, but those in the containment condition did not. These and control results indicated that, at 4.5 months of age, infants realize that the height of an object relative to that of an occluder determines whether the object can be fully or only partly hidden behind the

Renée Baillargeon*
Dept of Psychology, University of Illinois, 603 East Daniel, Champaign, IL 61820, USA.
*email: rbaillar@s.psych.uiuc.edu

Su-hua Wang
Dept of Psychology, University of Illinois, 603 East Daniel, Champaign, IL 61820, USA.

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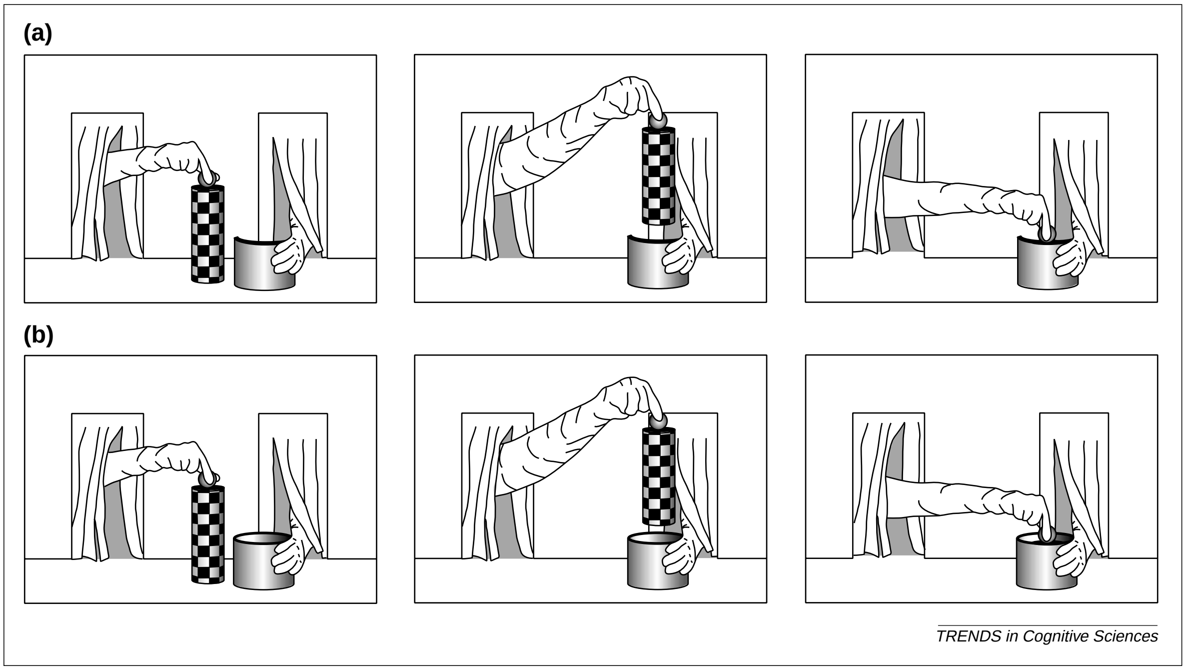


Fig. 1. Schematic drawing of the unexpected test events in the experiment of Hespos and Baillargeon [22]. (a) Occlusion condition. (b) Containment condition. (See text for discussion.)

occluder, but they do not yet realize that the height of an object relative to that of a container determines whether the object can be fully or only partly hidden inside the container.

The positive results obtained in the occlusion condition were confirmed in a second experiment in which the tall object was lowered behind, rather than inside, the tall and short containers. In this experiment, the containers served merely as occluders, and the infants again detected the violation in the unexpected event (see also Refs [23,24]).

In a third experiment, 5.5-, 6.5-, and 7.5-month-old infants were shown the containment condition test events. Only the 7.5-month-old infants looked reliably longer at the unexpected than at the expected event. These and control results indicated that it is not until infants are about 7.5 months of age that they begin to consider height information when predicting the outcomes of containment events.

Together, the results of these experiments suggested three conclusions. First, infants view occlusion and containment as distinct event categories. Second, infants do not generalize the variable height from occlusion to containment, even though it is relevant to both categories and invokes in each case the same general physical principles. Third, several months typically separate infants' acquisition of the variable height in occlusion and in containment events, resulting in a marked décalage in their responses to these events.

Height in containment and covering events

Building on the results of Hespos and Baillargeon [22], Wang *et al.* (unpublished data, reviewed in Ref. [25]) compared 9-month-old infants' ability to reason about the variable height in containment and in covering events. The infants saw either test events in which a tall object was lowered inside a container (containment condition; Fig. 2a), or test events in which a cover was lowered over the same tall object (covering condition; Fig. 2b). In all of the events, the object became fully hidden. In the expected events, the container or cover was slightly taller than the object; in the unexpected events, the container or cover was only half as tall, so that it should have been impossible for the object to become fully hidden (see Fig. 2). The tall and short covers were identical to the containers turned upside-down.

The infants in the containment condition looked reliably longer at the unexpected than at the expected event, but those in the covering condition did not. In a subsequent experiment, 11- and 12-month-old infants were tested with the covering condition events. Only the 12-month-old infants detected the violation in the unexpected event. These results, together with those discussed in the last section, indicated that, although infants recognize at about 7.5 months of age that the height of an object relative to that of a container determines whether the object can be fully or only partly hidden inside the container, it is not until infants are about 12 months of age that they realize that the height of an object relative to that of a cover determines whether the object can be fully or only partly hidden under the cover.

Transparency in occlusion and containment events

All of the experiments described in the preceding sections examined infants' reasoning about height information in various events. A recent series of experiments focused on a different variable, that of transparency. Luo and Baillargeon (unpublished data, reviewed in Ref. [25]) compared 8.5-month-old infants' reasoning about transparency information in occlusion and in containment events.

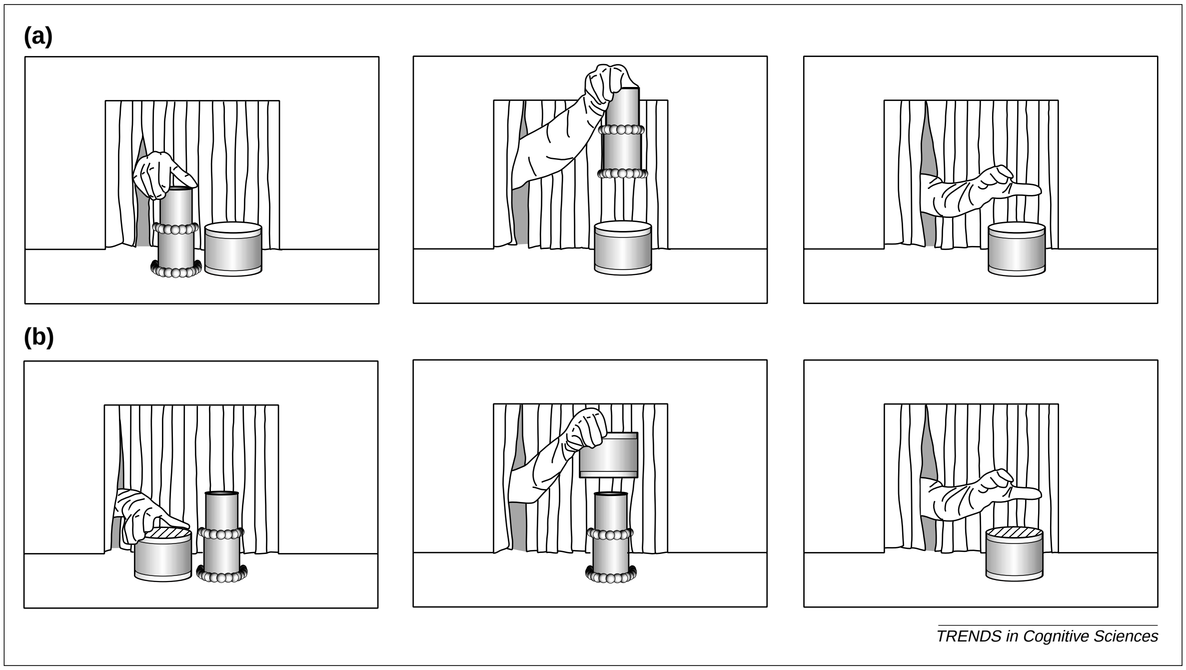


Fig. 2. Schematic drawing of the unexpected test events in the experiment of Wang *et al.* (unpublished data). (a) Containment condition. (b) Covering condition.

At the beginning of each test event, the infants saw either a transparent occluder (occlusion condition; Fig. 3a) or a transparent container (containment condition; Fig. 3b); to the right of the occluder or container was a slightly shorter object. First, an opaque screen was raised to hide the occluder or container. Next, the object was lifted above the screen and then lowered behind the transparent occluder or inside the transparent container. Finally, the opaque screen was removed to reveal the occluder or container once more. In the expected events, the object was visible through the front of the occluder or container. In the unexpected events, the object was absent (Fig. 3). The container was made of Plexiglas, and its edges were outlined with red tape; the occluder was identical to the front of the container.

The infants in the occlusion condition looked reliably longer at the unexpected than at the expected event, but those in the containment condition did not. In subsequent experiments, it was found that older, 10-month-old infants tested with the containment condition events succeeded in detecting the violation in the unexpected event; and that 7.5-month-old (but not 7-month-old) infants tested with the occlusion condition events were similarly successful. These and control results thus revealed another décalage in infants' reasoning about occlusion and containment events: infants realize at about 7.5 months of age that an object placed behind a transparent occluder should remain visible, but do not realize until about 10 months of age that an object placed inside a transparent container should also remain visible.

Conclusions

The experiments reported in the preceding sections suggest three general conclusions. First, infants appear to sort physical events into distinct categories, such as occlusion, containment, and covering events. Second, infants learn separately how each category operates. A variable identified in one category is not generalized to other relevant categories; rather, it is kept tied to the individual category where it was first acquired. Third, when weeks or months separate the acquisition of the same variable in two or more categories, striking décalages arise in infants' responses to events from the different categories. Thus, infants are surprised when a tall object becomes hidden behind but not inside a short container; when a tall object becomes hidden inside a short container but not under a short cover; and when an object becomes hidden behind a transparent occluder but not inside a transparent container.

Reasoning across event categories

If infants do form distinct event categories, one might expect them to respond differently, in some situations at least, when exposed to successive events from the same or from different event categories. How infants reason about an event from one category might affect – for better or for worse – their reasoning about a subsequent event from the same or from another category. To date, such category effects have been observed in three areas of infancy research: variable priming, perseveration, and object individuation.

Variable priming

Spelke has proposed that from birth core principles of continuity (objects exist continuously in time and space) and solidity (two objects cannot exist at the same time in the same space) guide infants' interpretation of physical events [11,17,26]. This proposal might be taken to suggest that infants, at all ages, should detect all salient violations of the continuity and solidity principles. As we saw in the previous sections, however, infants often fail to detect

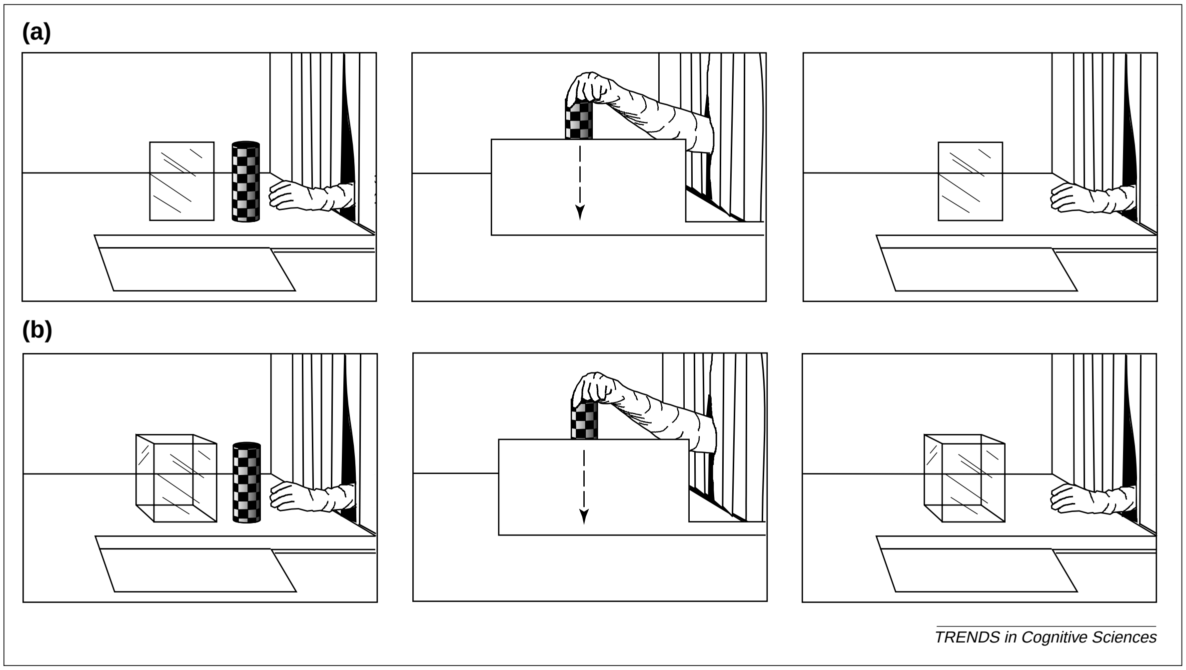


Fig. 3. Schematic drawing of the unexpected test events in the experiment of Luo and Baillargeon (unpublished data). (a) Occlusion condition. (b) Containment condition.

such core violations. Recall, for example, that 8.5-month-olds are not surprised when an object is placed inside a transparent container which is then revealed to be empty, and that 11-month-olds are not surprised when a short cover is lowered over a tall object until it becomes fully hidden.

Over the past few years, we have been developing an account of infants' physical reasoning that attempts to reconcile these and other similar failures with the proposal that infants possess core continuity and solidity principles [6,25,27,28]. This account assumes that, when watching a physical event, infants build a *physical representation* that includes basic spatial, temporal, and mechanical [15] information. This information is used, early in the representation process, to categorize the event. Infants then access their knowledge of the event category selected; this knowledge specifies the variables that have been identified as relevant to the event category and hence that should be encoded when representing the event. Both the basic and the variable information in the physical representation are interpreted in accord with infants' core principles.

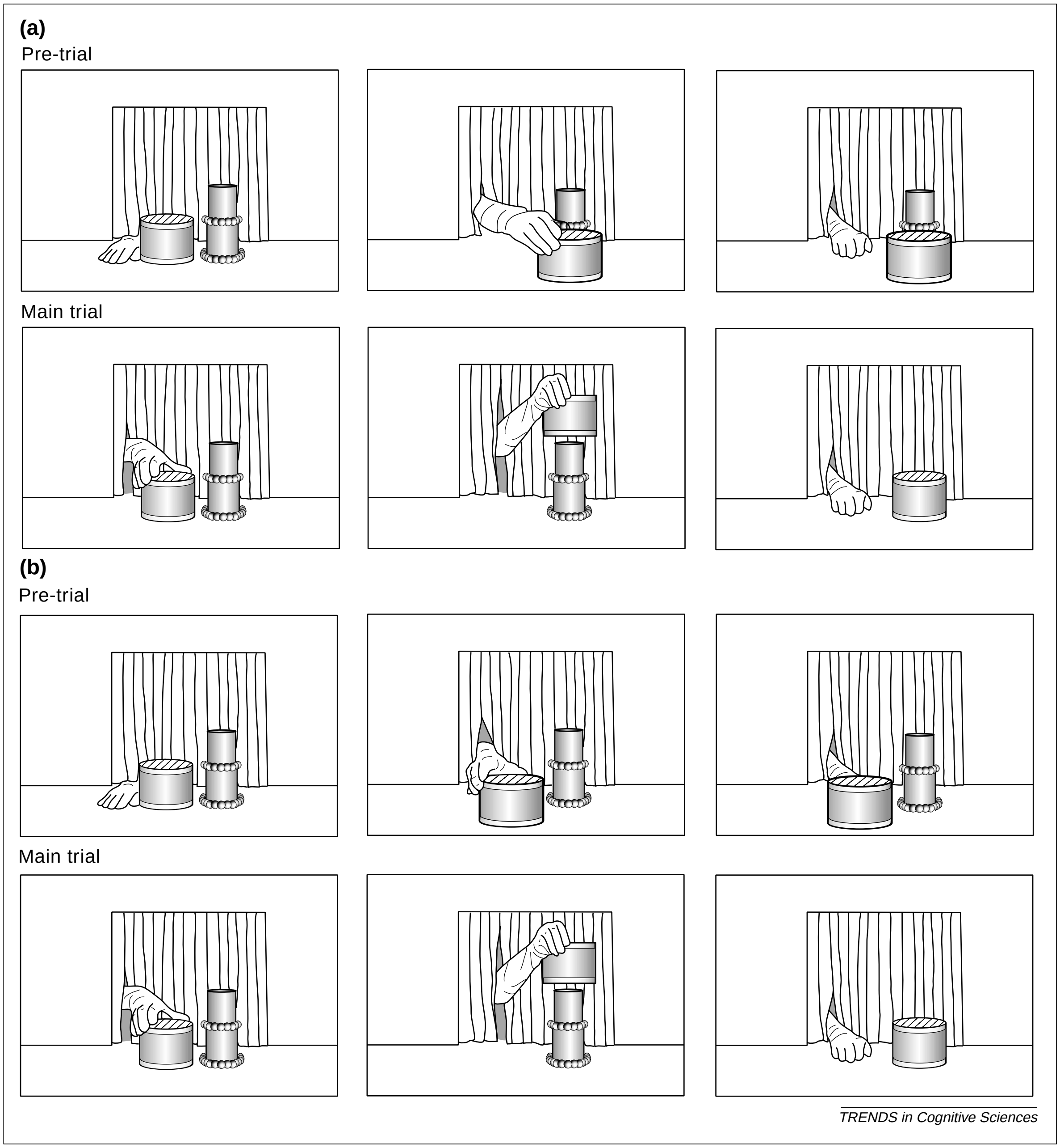
To illustrate this account, consider once again the finding that infants aged 11 months and younger are not surprised when a short cover is lowered over a tall object until it becomes fully hidden. Upon seeing the cover being lowered over the object, infants would categorize the event as a covering event and would then access their knowledge of this category. Because this knowledge does not yet include the variable height – which is typically not identified until about 12 months – infants would include no information in their physical representation about the relative heights of the cover and object. As a result, infants would be unable to detect the core violation in the event.

The preceding account makes an intriguing prediction. If infants could be 'primed' to include information about a key variable in their physical representation of an event, this information would then be interpreted in terms of their core principles, allowing them to detect core violations involving this key variable.

To test this prediction, we recently conducted a priming experiment with 8-month-old infants focusing on the variable height in covering events (Wang and Baillargeon, unpublished data, reviewed in Ref. [25]). The infants saw the same expected and unexpected covering events as in the experiment by Wang *et al.* (unpublished data) that was described earlier, with one exception. Prior to each test trial, the infants watched a pre-trial intended to prime them to attend to the relative heights of the cover and object (see Fig. 4a). In designing these pre-trials, we took advantage of the fact that height is identified as an occlusion variable very early, at about 3.5 months of age [23]. In each pre-trial, the cover was first slid in front of the object, to create an occlusion event; after 5 s, the cover was slid back to its original position, and then the trial proceeded as in Wang *et al.*'s experiment, with the cover being lowered over the object. We reasoned that the infants would categorize the event as an occlusion event and would then access their knowledge of this category; because this knowledge at 8 months includes the variable height, the infants would include information about the relative heights of the cover and object in their physical representation of the event. We speculated that this information might still be available (or might once again be included) when the infants next represented the covering event.

The results supported our prediction: the infants looked reliably longer at the unexpected than at the expected event, suggesting that the occlusion priming

Fig. 4. Schematic drawing of the unexpected test events in the experiment of Wang and Baillargeon (unpublished data). (a) Occlusion priming condition. (b) Display priming condition.

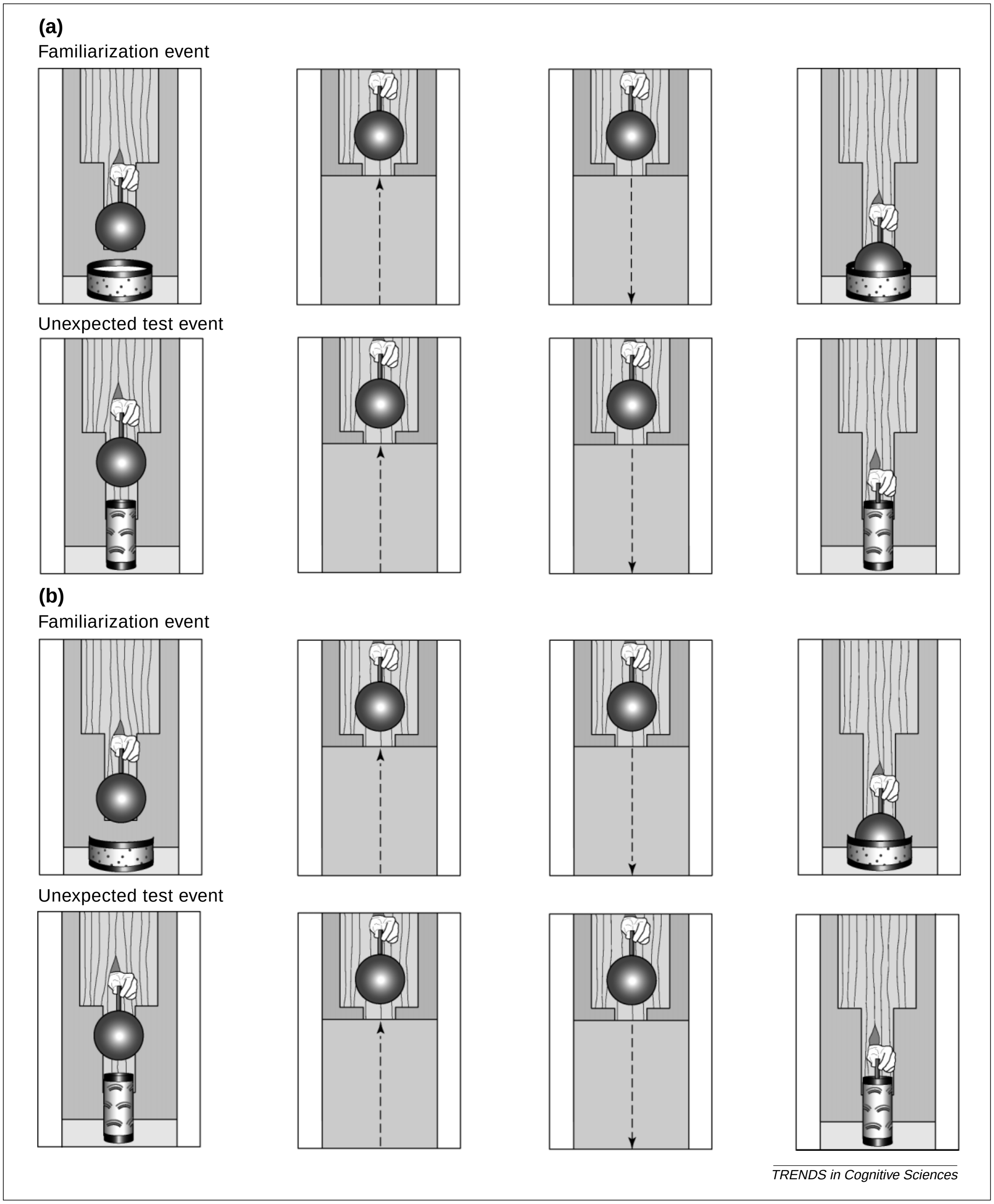


pre-trials led them to include the key height information in their representation of the covering event. This conclusion was supported by the results of a control condition with different pre-trials. In this condition, the cover was simply slid forward, next to the object, so that the infants saw a display rather than an occlusion event (Fig. 4b). These infants failed to detect the violation in the unexpected event, suggesting that they did not include information about the heights of the cover and object in their representation of either the display or the covering event.

Perseveration

When watching physical events, do infants always engage in the careful monitoring process described in the last section, attending to all of the variables they have identified as relevant to the events? Recent findings by Aguiar and Baillargeon [29] suggest that the answer to this question is negative. When infants are shown the same event repeatedly for several trials, they determine in a *preliminary analysis* at the start of each trial whether the event before them is similar or different from that on preceding trials. If they judge the event to be similar, infants do not engage in any careful monitoring of the event, but simply retrieve their previous prediction about its likely outcome. If they judge the event to be different, infants monitor it carefully and compute a new prediction about its likely outcome. This response pattern makes for efficient problem solving – as long as infants are accurate in their preliminary analyses. If infants fail to notice a crucial change and as a result mistakenly judge an event to be similar to that on preceding trials, they will retrieve their previous

Fig. 5. Schematic drawing of the familiarization and unexpected test events in the experiment of Aguiar and Baillargeon [29]. (a) Same-category condition. (b) Different-categories condition.



prediction instead of computing a new one, thus committing a perseverative error.

To explore infants' perseverative tendencies in a violation-of-expectation task, Aguiar and Baillargeon [29] conducted experiments focusing on 6.5-month-old infants' reasoning about the variable width in containment events; infants this age were known to be able to reason about this variable [30]. In one condition (same-category condition), the infants watched containment events during both familiarization and test (Fig. 5a). In the familiarization event, a ball attached to the end of a rod was lowered into a wide, shallow container. In the test events, the same ball was lowered into a tall container that was either slightly wider (expected event) or much narrower (unexpected event) than the ball; in either case, only the rod protruded from the rim of the container. In another condition (different-categories condition), the infants saw containment events during test but not familiarization: the bottom and back of the wide, shallow container were removed to create a rounded occluder (Fig. 5b).

The infants in the different-categories condition looked reliably longer at the unexpected than at the

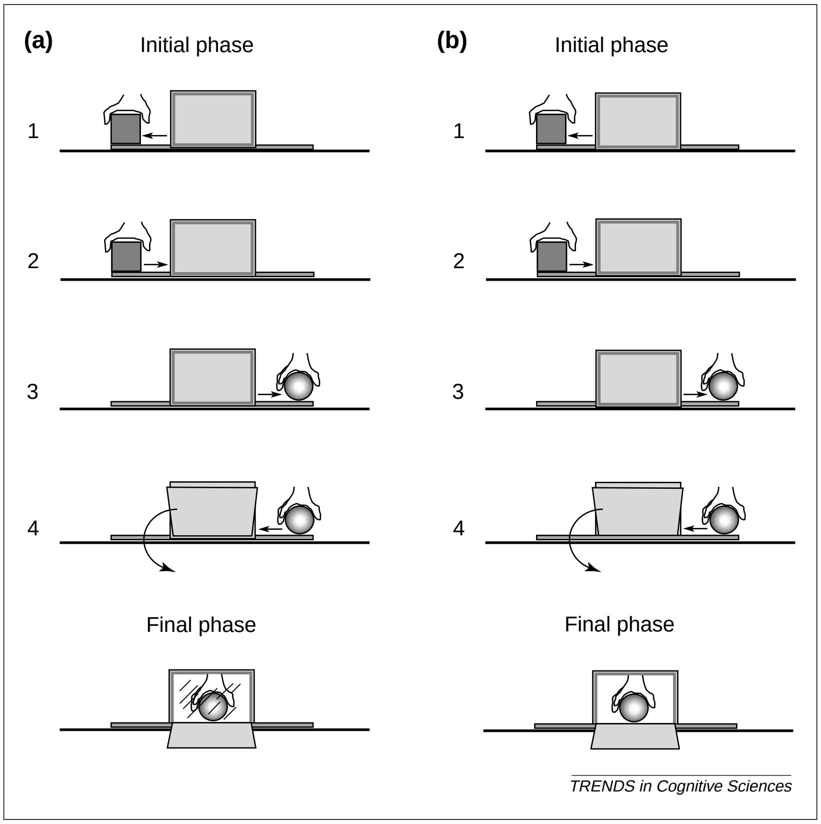


Fig. 6. Schematic drawing of the unexpected test trials in the experiment of Wilcox and Chapa [35] (a) Event-monitoring condition. (b) Event-mapping condition. (Redrawn with permission from the description in Wilcox *et al.* [36].)

expected event, but those in the same-category condition did not. Aguiar and Baillargeon [29] speculated that the infants in the same-category condition did not notice the change in the width of the container in their preliminary analyses of the test events. As a result, the infants judged the events to be similar to the familiarization event, and they retrieved the prediction they had formed for this event ('the ball will fit into the container'). Because this prediction was correct for the expected but not the unexpected event, the infants failed to detect the violation in the latter event. By contrast, the infants in the different-categories condition noticed in their preliminary analyses of the test events that these were from a different category than the familiarization event, namely, containment rather than occlusion. The infants thus judged the test events to be novel, computed appropriate predictions for their outcomes, and detected the violation in the unexpected event.

Additional experiments by Aguiar and Scott (unpublished data) confirmed and extended these initial results. First, 5.5-month-old infants tested in the same-category condition also responded perseveratively. Second, 5.5- and 6.5-month-old infants did not perseverate when tested with a novel version of the different-categories condition. This new version was similar to the last with one exception: during familiarization, the occluder was removed and the infants saw a simple display event in which the ball was lowered to the apparatus floor. Finally, further evidence of perseveration was obtained in new experiments focusing on the variable height in containment events (recall that this variable is identified at about 7.5 months of age [22]). After watching a tall object being repeatedly hidden in a very tall container, 9-month-old infants were not surprised to see the same object being hidden in a very short container (same-category condition); however, they did show surprise at this event when no container was present during familiarization and the tall object was simply lowered to the apparatus floor (different-categories condition).

Object individuation

The field of object individuation focuses on infants' ability to determine, when faced with an event, how many distinct objects are involved in the event. Current research suggests that, although infants typically succeed at individuating objects when given spatio-temporal information [27,31–33], the same is not true of featural information.

This last point was first uncovered by Xu and Carey [33]. In one experiment, 12- and 10-month-old infants received expected and unexpected test trials. During the initial phase of each trial, the infants repeatedly watched an occlusion event: an object (e.g. a ball) emerged from behind one edge of a screen and then returned behind it; next, a different object (e.g. a bottle) emerged from behind the other edge of the screen and again returned behind it. During the final phase, the screen was removed to reveal either one (unexpected trials) or both (expected trials) of the objects resting on the apparatus floor. Only the 12-month-old infants showed surprise during the unexpected trials. Xu and Carey concluded that the younger infants did not realize that two distinct objects were involved in the occlusion event. They speculated that 10-month-old infants still lack specific object concepts such as ball and bottle, and that these concepts are not acquired until word learning begins, at the end of the first year.

Although the negative finding Xu and Carey [33] obtained with the 10-month-old infants has been confirmed in additional experiments [32–36], their interpretation of this finding has been questioned. First, rhesus macaques succeed at similar tasks, despite their lack of language [37,38]. Second, pre-linguistic infants also succeed at similar tasks when processing demands are reduced [32,35,36,39–41]. For example, Wilcox and Schweinle [41] found that even 5.5-month-old infants show surprise during unexpected trials when the occlusion event is made very brief (e.g. the first object disappears behind one edge of the screen, the second object emerges from behind the other edge, and the screen is immediately lowered).

Wilcox and Baillargeon [32,40] have proposed a novel interpretation of the negative results obtained by Xu and Carey [33], which rests on the distinction between event-mapping and event-monitoring tasks. In an event-mapping task, infants see events from *two* different event categories and judge whether the two events are

Questions for future research

Infants are highly skilled at forming object categories, and use this categorical information for multiple purposes including organizing displays and inferring non-obvious properties of novel objects [43–46]. We have presented evidence here that infants also form event categories, and that these categories play an important role in their learning and reasoning about events. Many questions remain for future research, some of which are:

- What is the basis of infants' event categories? How are they formed?
- What are the limits of the priming method? Would positive effects be obtained if infants were primed with different objects, or the day prior to being tested?
- Can perseveration ever occur with events from different categories?
- Why do infants fail event-mapping tasks when they must use featural but not spatiotemporal information to individuate the objects in the first event?

consistent. In an event-monitoring task, infants see an event from *one* event category and judge whether the successive portions of the event are consistent. According to this scheme, the task devised by Xu and Carey is an event-mapping task: each test trial involves first an occlusion event (during the initial phase, when the objects emerge successively from behind the screen) and then a display event (during the final phase, when one or both objects rest on the apparatus floor). To succeed, infants must (1) retrieve their representation of the occlusion event and (2) map the objects in this representation onto those in the display event. The negative results obtained by Xu and Carey and others suggest that, under some conditions, young infants have difficulty completing this retrieval and mapping process.

The preceding analysis makes a number of interesting predictions, several of which have already been experimentally confirmed (for reviews, see Refs [36,42]). For example, in one experiment by Wilcox and Chapa, 9.5-month-old infants were assigned to an event-monitoring or an event-mapping condition, and again received expected or unexpected test trials composed of an initial and a final phase [35] (see Fig. 6). During the initial phase, a ball (expected trials) or a box (unexpected trials) emerged from behind the left edge of a screen and then returned behind it; next, the ball emerged from behind the right edge of the screen and again returned behind it. During the final phase, the central portion of the screen was lowered, leaving a thin rectangular frame; through this frame, the infants could see the ball resting alone on the apparatus floor. For the infants in the event-monitoring condition (Fig. 6a), the frame was filled with a clear plastic, to create a transparent screen; for the infants in the event-mapping condition (Fig. 6b), the frame was empty.

The infants in the event-monitoring condition looked reliably longer during the unexpected than the expected trials, but those in the event-mapping condition did not. According to Wilcox and Chapa [35], the infants tested with the empty frame faced an event-mapping task: they saw first an occlusion and then a display event, as in Xu and Carey's experiment [33], and they experienced the usual difficulty mapping the objects from one event onto the other. By contrast, the infants tested with the filled frame faced an event-monitoring task: they saw a single, ongoing occlusion event involving first an opaque and then a transparent occluder, and they easily kept track of the objects as the event unfolded.

Conclusions

The research reviewed in this final section suggests several conclusions about infants' representations of physical events. When watching an event, infants first categorize it and then access their knowledge of the category selected; this knowledge specifies the variables that have been identified as relevant to the category and should be included in the event representation. Under special priming conditions, however, infants can be induced to include a novel variable in their representation of an event, leading to more accurate predictions about the event's outcome. When presented with similar events repeatedly, infants judge in a preliminary analysis at the start of each event whether it is familiar (in which case they retrieve their prior prediction) or novel (in which case they compute a new prediction). Events from different event categories are consistently judged to be novel, suggesting that category information is a salient part of the preliminary analysis.

Finally, when presented with an occlusion event followed by a display or other event, infants sometimes have difficulty mapping the objects from the first to the second event. This result suggests that an event representation is maintained until a category change occurs, at which point a new event representation is set up; and that establishing links between successive representations can be challenging for young infants.

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Observing the transformation of experience into memory

Ken A. Paller and Anthony D. Wagner

The ability to remember one's past depends on neural processing set in motion at the moment each event is experienced. Memory formation can be observed by segregating neural responses according to whether or not each event is recalled or recognized on a subsequent memory test. Subsequent memory analyses have been performed with various neural measures, including brain potentials extracted from intracranial and extracranial electroencephalographic recordings, and hemodynamic responses from functional magnetic resonance imaging. Neural responses can predict which events, and which aspects of those events, will be subsequently remembered or forgotten, thereby elucidating the neurocognitive processes that establish durable episodic memories.

Some of life's episodes are remembered so well that we can accurately bring back to mind or recollect tremendous detail, even after considerable time has elapsed. Other events are seemingly experienced in an identical way, and yet are irretrievably lost from memory, even moments later. A fundamental challenge for memory theorists is to specify the neurocognitive processes that impact the mnemonic fate of our experiences, influencing whether they will be remembered or forgotten. A significant step towards meeting this challenge is to delineate encoding operations and their impact on subsequent memorability. Although multiple factors influence our ability to remember, one factor that must be critical for remembering is whether the experience coincides with the effective laying down of an engram in the brain. Insights into effective memory formation can be gained by monitoring brain activity during an experience and relating these neural measures to behavioral evidence that a memory was formed. In this review, we consider how correlations between neural activation and subsequent remembering have informed our theories of how experiences are transformed into memories.

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