Infants Can Use Temporary or Scant Categorical Information to Individuate Objects

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Abstract

In a standard individuation task, infants see two different objects emerge in alternation from behind a screen. If they can assign distinct categorical descriptors to the two objects, they expect to see both objects when the screen is lowered; if not, they have no expectation at all about what they will see (i.e., two objects, one object, or no object). Why is contrastive categorical information critical for success at this task? According to the *kind* account, infants must decide whether they are facing a single object with changing properties or two different objects with stable properties, and access to permanent, intrinsic, kind information for each object resolves this difficulty. According to the *two-system* account, however, contrastive categorical descriptors simply provide the object-file system with unique tags for individuating the two objects and for communicating about them with the physical-reasoning system. The two-system account thus predicts that *any type of contrastive categorical information, however temporary or scant it may be,* should induce success at the task. Two experiments examined this prediction. Experiment 1 tested 14-month-olds (N = 96) in a standard task using two objects that differed only in their featural properties. Infants succeeded at the task when the object-file system had access to contrastive *temporary* categorical descriptors derived from the objects' distinct causal roles in preceding support events (e.g., formerly a support, formerly a supportee). Experiment 2 tested 9-month-olds (N = 96) in a standard task using two objects infants this age typically encode as merely featurally distinct. Infants succeeded when the object-file system had access to *scant* categorical descriptors derived from the objects' prior inclusion in static arrays of similarly shaped objects (e.g., block-shaped objects, cylinder-shaped objects). These and control results support the two-system account's claim that in a standard task, contrastive categorical descriptors serve to provide the object-file system with unique tags for the two objects.

Keywords:

infant cognition; physical reasoning; object individuation; categorical information; event role; basic-level category

Highlights:

- Infants typically individuate only objects with distinct categorical descriptors.
- In the two-system account, *any* type of categorical information can lead to success.
- We tested two types of categorical information not used before in individuation tasks.
- 14-month-olds succeeded with temporary role-based descriptors from former events.
- 9-month-olds succeeded with scant descriptors derived from static shape-based arrays.

1. Introduction

Decades of research on infant physical reasoning have revealed that the ability to reason about objects' causal interactions in simple physical events develops gradually over the first two years of life (for a review, see Lin et al., 2022). At least two factors contribute to this protracted development. The first is that infants must identify, for each event category (e.g., occlusion, containment, support, and collision events), what features of objects and their arrangements are causally relevant for predicting outcomes. With respect to occlusion features, for example, infants typically identify height and width—or size more generally—by 3.5 months (Baillargeon & DeVos, 1991; Wang et al., 2004), shape by 4.5 months (Wilcox, 1999; Wilcox & Baillargeon, 1998b), pattern by 7.5 months (Wilcox, 1999), and color by 11.5 months (Lin et al., 2021; Wilcox, 1999). The evidence that infants have identified these occlusion features comes from a variety of tasks. In the case of height and width information, for example, infants ages 3.5−6 months detect an interaction violation if a tall object becomes hidden behind a short occluder (Baillargeon & DeVos, 1991; Hespos & Baillargeon, 2001; Mou & Luo, 2017) or if a wide object becomes hidden behind a narrow occluder (Wang et al., 2004); they detect a change violation if a large ball changes into a small one when passing behind an occluder too narrow to hide both balls (Wilcox, 1999); they detect a change violation if a tall object changes into a short one, or if a wide object changes into a narrow one, when briefly held behind a large occluder (Goldman & Wang, 2019); and they reach preferentially for a tall as opposed to a short occluder when searching for a tall object (Hespos & Baillargeon, 2006).

The second factor that contributes to the protracted development of early physical reasoning is that infants who have identified features as relevant to an event category nevertheless fail to use these same features to individuate objects in events from the category (Xu & Carey, 1996; Xu et al., 2004). For example, when 12-month-olds see two objects that differ in size (e.g., a small and a large ball, both red and covered with glitter), in color (e.g., a ball with pink and green stripes and a ball with purple and orange stripes), or in size, pattern, and color (e.g., a small soccer ball with orange, green, and white hexagons and a large red ball covered with glitter) emerge in alternation from behind a large occluder, they fail to detect an individuation violation when the occluder is finally removed to reveal only one of the objects (Xu et al., 2004).

In this article, we focus on this second factor. Why do infants who have identified features as causally relevant for occlusion events fail to use these features when individuating objects? If infants detect a change violation when a single object surreptitiously changes size, pattern, or color behind an occluder (Goldman & Wang, 2019; Lin et al., 2021; Wang & Baillargeon, 2006; Wilcox, 1999), why do they fail to establish separate representations when two objects that differ in size, pattern, or color emerge in alternation from behind an occluder?

Ever since the discovery of infants' baffling difficulty at individuating objects, researchers have been seeking to understand its cause. Over the course of these investigations, additional findings have come to light that have helped inform the quest for an explanation. Our article had two main goals. The first was to review key findings from standard and modified individuation tasks and to discuss three accounts that have been proposed for these findings: the kind account, the mapping account, and the more recent two-system account. As will become clear, the two-system account borrows heavily from the earlier accounts but still differs from them in critical respects. In particular, although the kind and two-system accounts agree that categorical information plays an essential role in infants' ability to individuate objects, they differ widely in their claims about why this information matters and, relatedly, about what types of categorical information can support infant individuation. The second goal of our article was to examine these competing claims experimentally, using two novel manipulations.

1.1. Findings on infant individuation

In this section, we summarize findings on infant individuation from standard tasks and from two modified tasks. These findings have brought to light both strengths and limitations in infants' ability to individuate objects.

1.1.1. Standard tasks

In *standard* tasks, infants see a sequence of two events (see Figure 1). In the first event, two different objects are brought out in alternation from a hiding location; the second event varies across tasks but is intended to assess whether infants correctly individuated the two objects in the first event. In some tasks, infants see an occlusion event followed by a no-occlusion event. The two objects first emerge in alternation on either side of a large screen, which is then lowered to reveal only one of the objects; surprise at this violation is taken to indicate that infants correctly inferred how many objects were present behind the screen (we refer to these tasks as *standard-violation* tasks; Wilcox & Baillargeon, 1998a; Xu & Carey, 1996). In other tasks, infants see a containment event followed by a search event. The two objects are first lifted in alternation from inside a large box, which is then moved within infants' reach; persistent searching after one object has been retrieved is taken as evidence that infants correctly inferred how many objects were present inside the box (we refer to these tasks as *standard-search* tasks; Van de Walle et al., 2000).

A wealth of research indicates that infants succeed at standard tasks only if they are able to assign the two objects introduced in the first event to *distinct categories*. Because there is substantial development with age in what categorical information infants spontaneously encode about objects, whether they succeed at a task depends on (a) whether the two objects are categorically distinct in some way and (b) whether this categorical distinction is one that infants happen to encode at the age they are tested.

Prior to their first birthday, most infants do not spontaneously encode an isolated object's basic-level category, such as toy duck, ball, or block (Pauen, 2002; Xu & Carey, 1996). However, they do encode broad, *ontological* categorical information, such as whether the object is human or non-human (Bonatti et al., 2002; Kibbe & Leslie, 2019), animate or inanimate (Setoh et al., 2013; Surian & Caldi, 2010), and self-propelled or inert (Decarli et al., 2020; Luo et al., 2009). Thus, 9–10-month-olds succeed at standard tasks when tested with a humanlike vs. a non-humanlike object (e.g., a doll vs. a toy dog; Bonatti et al., 2002; see also Bonatti et al., 2005; Stavans et al., 2019), an animate vs. an inanimate object (e.g., a flying bee vs. a block carried by a hand; Surian & Caldi, 2010), or a self-propelled vs. an inert object (e.g., a self-propelled ball vs. an identical ball carried by a hand; Decarli et al., 2020).

Around their first birthday, infants begin to spontaneously encode objects' *basic-level* categories (Pauen, 2002; Xu & Carey, 1996). As a result, infants now also succeed at standard tasks when tested with two objects from different basic-level categories such as a toy duck vs. a ball (Xu & Carey, 1996), a ball vs. a block (Wilcox & Baillargeon, 1998a), or a toy telephone vs. a toy book (Van de Walle et al., 2000).

Critically, the main point from these investigations is not that infants succeed at standard tasks when they can encode categorical information about the two objects shown in the first event, and fail otherwise: As the preceding descriptions indicate, infants always encode categorical information about the objects (e.g., a ball and a block might both receive categorical descriptors such as non-humanlike, inanimate, rigid, and closed). Rather, the main point is that infants succeed when they can assign one or more *distinct* categorical descriptors to the two objects, and fail otherwise. Thus, prior to 12 months, infants fail if tested with two objects they encode as belonging to the same ontological categories and differing only in their featural properties (e.g., a toy duck vs. a ball; Xu & Carey, 1996; see also Bonatti et al., 2002; Stavans et al., 2019; Van de Walle et al., 2000; Wilcox & Baillargeon, 1998a). Similarly, at 12 months, infants fail if tested with two objects they encode as belonging to the same ontological and basic-level categories and differing only in their featural properties (e.g., a small yellow cup decorated with green and red stripes and fitted with an orange handle vs. a large semi-transparent cup decorated with multicolored shapes and fitted with a blue handle; Xu et al., 2004; see also Bonatti et al., 2005).

Although prior to 12 months infants do not yet encode objects' basic-level categories, they can be induced to do so via various experimental manipulations, with positive effects on their individuation performance (Futó et al., 2010; Stavans & Baillargeon, 2018; Xu, 2002). For example, in standard-violation tasks, 9-month-olds succeeded with a *lexical* manipulation: As each object emerged into view in the occlusion event, an experimenter gave the object a distinct label (e.g., "Look, [baby's name], a duck!", "Look, [baby's name], a ball!"; Xu, 2002). Similarly, 10-month-olds succeeded with a *pedagogical-functional* manipulation: As each object was brought out in the occlusion event, an experimenter produced ostensive-communicative signals ("Hi baby, hi!") and demonstrated the object's distinct function (e.g., a radio that played a melody when its dial was turned, a lamp that flashed small lights when its handle was pulled; Futó et al., 2010). Finally, even 4-month-olds succeeded with a prior *functional* manipulation: In two introduction trials, an experimenter demonstrated two simple tools' distinct functions (e.g., a masher that was used to compress sponges, tongs that were used to pick them up); next, in a test trial, the two tools emerged in alternation from behind a screen, which was then lowered to reveal only one of the tools (Stavans & Baillargeon, 2018).

The preceding findings make clear that contrastive categorical information, whether encoded spontaneously or via experimental manipulations, enables infants to succeed at standard tasks. Strikingly, when such information is unavailable, infants fail at standard-violation tasks not only when the screen is lowered to reveal only one of the objects, but also when it is lowered to reveal *no objects at all*. Thus, after seeing two red cups that differed only in pattern (yellow stripes vs. green dots) emerge in alternation from behind a screen, 12-month-olds failed to detect a violation when the screen was lowered to reveal either one cup or no cup. If the same cup appeared on either side of the screen, however, infants expected to see one cup and were surprised to see no cup, making clear that they were not simply confused by the no-cup outcome (Stavans et al., 2019). Similar results were found in a novel standard-violation task involving a containment event followed by a shaking event. To start, 9-month-olds saw a toy wolf and a ball being lifted in alternation from inside a large box. Next, the box was shaken vigorously yet produced *no impact sounds at all*, as though empty. Infants failed to detect a violation in this outcome, though they did expect to hear impact sounds if they saw both objects simultaneously, or a single object, at the start of the event (Stavans et al., 2019).

Together, the results reviewed in this section point to three conclusions. First, infants succeed at a standard task when they can assign distinct categorical descriptors to the two objects shown in the first event. Second, when they are unable to do so and encode the two objects as merely featurally distinct, they fail at the task. Finally, unsuccessful infants are not merely uncertain about whether one or two objects should be present in the second event: Rather, they hold no expectation at all about the event, resulting in a catastrophic failure.

1.1.2. One-Event tasks

We have just seen that infants fail at standard tasks when they encode the two objects shown in the first event as categorically similar and differing only in their featural properties. Are there circumstances in which infants demonstrate successful individuation even though they have to rely on the objects' featural differences to do so? Modified tasks such as one-event tasks (described in this section) and remainder tasks (described in the next section) provide a positive answer to this question (see Figure 1).

In *one-event* tasks, infants see a single, ongoing occlusion event involving two objects, and their ability to individuate the objects is assessed during the event itself. In some tasks, a transparent panel stands behind the screen and is revealed when the screen is lowered; infants thus see a continuing occlusion event involving first an opaque and then a transparent occluder. Wilcox and Chapa (2002) found that under these conditions, 9.5-month-olds succeeded in individuating a ball and a block (recall that at this age infants encode such objects as categorically similar and differing only in their featural properties). After seeing the two objects emerge in alternation from behind a large screen, infants detected a violation if the screen was lowered to reveal only the ball visible behind the transparent panel; this effect was eliminated, as usual, when the panel was absent. Stavans et al. (2019) replicated this finding in a one-event task testing 10-month-olds with two different female dolls: One was a light-skinned, blue-eyed blonde whose long hair was decorated with blue streaks and worn in two braids, and the other was a dark-skinned, brown-eyed brunette whose long, loose hair was decorated with a bow (there were thus multiple featural differences, including size, shape, and pattern differences, that infants could use to distinguish the dolls). After seeing the two dolls emerge in alternation from behind a large screen, infants detected a violation if the screen was lowered to reveal only one of the dolls behind the transparent panel; this effect was eliminated when no panel was present.

Other one-event tasks come from neuroimaging studies conducted by Wilcox and her colleagues using functional near-infrared spectroscopy (Wilcox et al., 2012, 2014). In these tasks, objects appeared in alternation on either side of a large screen: a green ball and a green block (different-shapes event), a green ball and a red ball (different-colors event), or the same green ball (same-object event). Each event was repeated twice, and then the trial ended; the screen was never lowered, so that infants saw a single, ongoing occlusion event. During the event, activation was recorded in infants' anterior temporal cortex, a brain region previously shown to be involved in the individuation process (Wilcox et al., 2010). Relative to the same-object event, 11.5-month-olds showed increased activation to both the different-shapes and different-colors events, whereas 5−7.5-month-olds showed increased activation to the different-shapes event only. Thus, consistent with prior findings (reviewed earlier) on the typical ages at which different occlusion features are identified, the older infants included shape and color information in their event representations and inferred that two objects were involved in both the different-shapes and different-colors events. In contrast, the younger infants included only shape information and inferred the presence of two objects in the different-shapes event only.

The one-event tasks described above suggest the following conclusion. When infants see two objects they encode as categorically similar emerge in alternation from behind a screen, they can give evidence of successful individuation if (a) they have identified one or more of the features that distinguish the objects as causally relevant for occlusion events and (b) their ability to individuate the objects is assessed during the occlusion event itself.

1.1.3. Remainder tasks

Remainder tasks provide further evidence that under certain circumstances infants can demonstrate successful individuation even when tested with objects they encode as differing only in their featural properties. These tasks are similar to standard tasks with one exception: At the end of the first event, only one object remains in the hiding location, because the other object is in a different location.

In some tasks, only one object is in the hiding location at the end of the first event because the other object has been left out in plain view. For example, in studies by Wilcox and her colleagues (Wilcox & Baillargeon, 1998a; Wilcox & Schweinle, 2002), 5.5–9-month-olds first saw a block move along a platform and disappear behind a large screen. Next, a ball emerged on the other side of the screen and paused in full view on the platform. The screen was then lowered to reveal no block—only the ball could be seen to the right of the screen. Infants detected the violation in this outcome, suggesting that (a) they correctly individuated the block and the ball based on the featural information available, (b) they realized that the block was still behind the screen, and (c) they expected to see the block when the screen was lowered. In another study in this series (McCurry et al., 2009), the screen was made of cloth fringe; after the ball emerged from behind the screen and paused, the platform and screen were moved within infants' reach. Infants reached significantly more for the screen than for the ball, suggesting that they believed the block was behind the screen and they wanted to retrieve it by reaching through the fringed screen. In both studies, the effect was eliminated when just the ball appeared on either side of the screen.

The preceding studies all used a very brief occlusion event, with no reversal in the movement path of either object, but similar results have been found with longer occlusion events. In one study with 11-month-olds, for example, two blocks that differed only in pattern were brought out three times in alternation from behind a large screen, and the last block to be brought out was left in plain view to the left of the screen (Lin & Baillargeon, 2019). Infants detected a violation when the screen was lowered to reveal no block, so that the only block visible was the one next to the screen. This effect was eliminated, as usual, if both blocks were returned behind the screen before it was lowered.

In other remainder tasks, only one object is in the hiding location at the end of the first event because the other object has been visibly moved out of the apparatus. For example, in a remainder study by Stavans et al. (2019) adapted from their novel standard-violation task described earlier, 9-month-olds first saw a toy wolf and a ball being lifted in alternation from inside a large box. Next, the last object lifted was removed from the apparatus, so that only the other object remained inside the box. When the box was next shaken, infants expected impact sounds, suggesting that (a) they correctly individuated the two objects based on the featural information available, (b) they realized that one object was still inside the box, and (c) they expected this object to collide noisily with the rigid walls of the box during the shaking.

The remainder tasks described above suggest the following conclusion. When infants see two objects they encode as categorically similar emerge in alternation from a hiding location, and this first event is followed by a second event designed to assess their ability to individuate the objects, infants succeed at the task if (a) they have identified one or more of the features that distinguish the objects as causally relevant for the event category depicted in the first event (e.g., occlusion, containment) and (b) only one object remains in the hiding location at the end of the first event.[1]

1.2. Kind and mapping accounts

Over the past three decades, several accounts have been offered for the findings reviewed

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[1] Although we are focusing in this article on individuation tasks that introduce two objects in the first event, results from a *switch* task that introduces a single object echo those of remainder tasks. In this task (Xu & Baker, 2005), 10-month-olds first saw a single object (e.g., a toy duck) being lifted two or six times from inside a large box. Next, the box was moved within infants' reach. When infants retrieved a different object (e.g., a toy book) from the box, they persisted in searching, as though they realized that the object they had seen before (e.g., the toy duck) must still be in the box. Here again, a single object was present in the hiding location at the end of the first event, and infants were able to use their representation of the event to guide their behavior in the second event.

in the previous section. In this section, we focus on two long-standing accounts, the kind and mapping accounts; in the next section, we introduce the more recent two-system account, which builds on these earlier accounts.

The kind and mapping accounts offer different explanations for infants' failure at standard tasks when tested with two objects they encode as merely featurally distinct. The kind account portrays this failure as an individuation failure: Infants are unable to use the featural information available to determine how many objects are involved in the first event. In contrast, the mapping account portrays this failure as a mapping failure: Infants can use the featural information available to establish separate representations for the two objects in the first event, but they have difficulty using these feature-based representations when interpreting the second event.

1.2.1. Kind account

The kind account holds three main assumptions (Carey, 2009; Xu, 2002, 2007, 2023; Xu & Baker, 2005; Xu & Carey, 1996, 2000; Xu et al., 2004). First, infants succeed at standard tasks when they can assign the two objects to distinct *kinds* (and more specifically sortals, the subset of kind concepts having to do with object concepts). Kinds are stable, long-term object categories, often with causally or functionally related features, that support individuation and identification; members of a kind share a number of intrinsic, stable properties and cannot spontaneously change into members of a different kind. This means that if two objects emerge in alternation from behind a screen and infants represent each object as belonging to a different kind, they can infer the presence of two objects because they understand that objects cannot spontaneously change kinds.

Second, infants are initially able to represent only a few kinds, such as inanimate objects, self-propelled objects, animate entities, and humanlike entities (some of these findings were initially taken to support the object-first hypothesis, the human-first hypothesis, and so on; Bonatti et al., 2002; Decarli et al., 2020; Surian & Caldi, 2010; Xu & Carey, 1996). By their first birthday, however, infants can also represent basic-level kinds such as ball, cup, and toy duck. At least three processes are thought to contribute to infants' acquisition of basic-level kinds: (a) as they interact with objects, infants gradually learn for each object kind what featural properties remain constant over time; (b) as they hear object labels, infants innately assume that distinct labels refer to distinct object kinds; and (c) as they observe objects' functional demonstrations, infants innately assume that distinct functions specify distinct object kinds.

Finally, although contrastive kind information is necessary for success at standard tasks, contrastive featural information may be sufficient for success at modified tasks with lower information-processing demands, such as one-event and remainder tasks. As we saw in the last section, these tasks have one event rather than two (one-event tasks), or they have one object rather than two in the hiding location at the end of the first event (remainder tasks). These reduced processing demands allow infants to correctly individuate objects based on their featural differences alone.

Although the kind account provides a possible explanation for many of the findings we have discussed, it leaves several questions unanswered. First, consider once again the findings of Xu et al. (2004). If by 12 months most infants have acquired the basic-level kind 'ball' and understand that balls do not spontaneously change featural properties, why do they fail at standard tasks involving two balls that differ in size, color, and pattern? Second, the kind account refers to standard tasks as "is-it-one-or-two" tasks (Xu, 2007) and assumes that unsuccessful infants are uncertain whether the hiding location holds a single object with changing properties or two different objects with stable properties. As we have seen, however, unsuccessful infants are not surprised even when given evidence that there are no objects at all in the hiding location. Finally, it is unclear why contrastive kind information is necessary for success at standard tasks, whereas contrastive featural information is sufficient for modified tasks such as one-event and remainder tasks. After all, the differences between standard and modified tasks can be rather subtle. For example, in all of these tasks, infants might see two objects emerge the same number of times from behind a screen; the tasks might differ only in that (a) a transparent panel is revealed when the screen is lowered (one-event tasks) or (b) the last object to emerge is left out in view before the screen is lowered (remainder tasks). Why do these task modifications allow infants, from a young age, to individuate objects they encode as merely featurally distinct? What mechanisms might be at play?

1.2.2. Mapping account

The mapping account holds three main assumptions (Needham & Baillargeon, 2000; Wilcox, 2003; Wilcox & Baillargeon, 1998a; Wilcox & Chapa, 2002; Wilcox & Schweinle, 2002; Wilcox et al., 2003). First, when tested with a standard task, infants correctly individuate the two objects in the first event as long as these differ (a) in their categorical descriptors or (b) in one or more features infants have identified as causally relevant for the event's category. This is because infants' physical reasoning is assumed to be innately constrained by a principle of *persistence*, which states that all other things being equal, objects persist in time and space with all of their properties (Baillargeon, 2008; Lin et al., 2022). Thus, if two objects that differ in size, pattern, and color emerge in alternation from behind a screen, and infants have identified these features as relevant for occlusion events, they can infer that two objects are present because they realize that objects cannot spontaneously change categorical descriptors or featural properties.

Second, to succeed at a standard task, infants must not only be able to establish separate representations for the two objects in the first event: They must also be able to use these object representations when interpreting the second event. This is referred to as a *mapping* process: Infants must retrieve the object representations they established during the first event and map them onto the objects in the second event, to judge whether the two events are consistent. Importantly, whereas category-based object representations are easily mapped from the first onto the second event, feature-based object representations are not. It is assumed that categorical descriptors act as summary object representations. When retrieved for the mapping process, these summary representations take up fewer information-processing resources than do lists of featural properties and, as such, they make the process easier for infants to complete.

Third, in certain tasks, infants can demonstrate that they correctly individuated the two objects shown even when they had to rely on featural information to establish the objects' representations. Thus, infants succeed at using feature-based object representations in one-event tasks because there is no mapping process required: Infants see a single, ongoing event, and they simply monitor its progress to assess whether it is consistent with their physical knowledge. Moreover, although remainder tasks, like standard tasks, do present infants with a sequence of two events and require mapping, the fact that only one object is in the hiding location at the end of the first event makes the mapping of feature-based object representations easier to complete.

Like the kind account, the mapping account provides an explanation for many of the findings we have reviewed but still leaves several questions unanswered. In particular, why are infants who fail at standard tasks not surprised even when given evidence that there are no objects at all in the hiding location? Shouldn't the disappearance of two objects register as a persistence violation? Second, the mapping account offers little detail about the nature of the mapping process, the difficulties it causes, and the mechanisms by which categorical descriptors help infants overcome these difficulties. Finally, the mapping account also offers little information about the differences between mapping tasks with high processing demands, such as standard tasks, and mapping tasks with fewer processing demands, such as remainder tasks.

1.3. The two-system account

The two-system account incorporates two chief notions from the accounts discussed in the previous section. One notion, borrowed from the kind account, is that contrastive categorical information is critical for success at standard tasks. The other notion, borrowed from the mapping account, is that particular processes come into play when an event comes to an end, so that infants respond differently when faced with a single, ongoing event as opposed to a sequence of events involving the same objects. As will become clear, however, the two-system account offers different explanations for these notions.

According to the two-system account, infants' successes and failures at standard and modified individuation tasks cannot be understood without spelling out in some detail the *cognitive architecture* that underlies infants' reasoning about physical events (Baillargeon et al., 2012; Levine & Baillargeon, 2016; Lin et al., 2021, 2022; Stavans et al., 2019). As such, the account builds on related work from the adult and infant literatures (Gordon & Irwin, 1996; Huttenlocher & Lourenco, 2007; Kahneman et al., 1992; Leslie et al., 1998; Pylyshyn, 2007; Rips et al., 2006; Simons & Levin, 1998; Zacks, 2010) and is summarized here in terms of four assumptions.

First, when infants begin to attend to a physical event, at least two cognitive systems become involved, the *object-file* (OF) system (Gordon & Irwin, 1996; Kahneman et al., 1992; Leslie et al., 1998) and the *physical-reasoning* (PR) system (Lin et al., 2021, 2022; Stavans et al., 2019). The OF system builds a temporary file for each attended object using incoming perceptual information as well as information stored in memory, and it updates the file as additional information becomes available. Each file contains identity ("what") and spatiotemporal ("where") information, and each type of information includes categorical descriptors and fine-grained features. The PR system brings to bear its physical knowledge to represent the causal interaction depicted in the event and to predict how it will unfold; this physical knowledge includes core principles (persistence, gravity, and inertia), core concepts, and learned rules identifying causally relevant features for each event category. During the event, the OF and PR systems exchange information in two main ways. To start, the OF system passes on to the PR system the identity and spatiotemporal categorical descriptors in its object files; the PR system then uses that information to identify the event's category (e.g., an occlusion event) and to assign event-specific causal roles to the objects in the event (e.g., occluder, occludee). Next, the PR system taps the OF system for information about previously identified features for the event category selected (e.g., at 12 months, this would include information about the relative sizes of the occluder and occludee as well as information about the shape, pattern, and color of the occludee). This featural information is then added to the event's representation, updated as it changes, and interpreted by the PR system using its physical knowledge.

Second, because the OF system uses categorical information to individuate objects whereas the PR system uses both categorical and featural information, disagreements can arise between the two systems. To illustrate, imagine that 12-month-olds see an occlusion event in which two balls that differ in size, pattern, and color emerge in alternation from behind a screen. The OF system will conclude, based on the identity and spatiotemporal categorical descriptors at its disposal, that *a single object* is involved in the event. In contrast, the PR system will conclude, based on the featural information it added to the event's representation, that *two distinct objects* are involved in the event. As one-event tasks demonstrate, this disagreement will matter little during the event itself because the PR system will be in charge of guiding infants' responses: Its interpretation (two objects) will *take precedence* over that of the OF system (one object), leading infants to respond correctly to the event.

Third, when an event ends, the OF and PR systems must agree on the number of objects present for the event's representation to be placed in memory and available to guide infants' interpretation of the next event. Returning to our occlusion event, if the OF system (one object) and the PR system (two objects) initially disagree about how many objects are present, but this disagreement can be reconciled as the event comes to a close, the event's representation can still be stored in memory. As remainder tasks demonstrate, reconciliation is possible if the two objects occupy *distinct locations* before the screen is lowered. The OF system will signal that a single object is present, next to the screen, whereas the PR system will signal that in addition to that object, there is another object present, behind the screen. Because *the two objects have distinct spatiotemporal categorical descriptors* (e.g., next to vs. behind the screen), the OF system will be able to open a file for the second object. As the OF and PR systems now agree that two objects are present, the event's representation will be stored in memory, enabling infants to correctly interpret the next event.[2]

Finally, as standard tasks demonstrate, reconciliation between the OF and PR systems is not possible if the two objects are both in the hiding location as the first event comes to an end. Returning to our occlusion event, although the PR system may signal that two objects are present

[2] The assumption that the OF system can open a second object file in a remainder task because it has access to distinct spatiotemporal categorical descriptors for the two objects echoes prior positive findings obtained with various spatiotemporal descriptors in individuation tasks. For example, the OF system successfully infers that two objects are present in an occlusion event (a) if the two objects are simultaneously visible at some point in the event (Xu & Carey, 1996; Xu et al., 2004); (b) if there is a gap in the screen and neither object appears in the gap (Spelke et al., 1995; Xu & Carey, 1996); or (c) if one object reappears from behind the screen too soon to have traveled the distance behind the screen (Wilcox & Schweinle, 2003).

behind the screen, the OF system will not be able to act on this prompt and open a file for the second object *because it lacks a unique categorical descriptor or tag for the object*. As stated above, the OF system can use only contrastive categorical information to individuate two objects: It cannot use spatiotemporal featural differences (e.g., one object is resting on the left behind the screen, and the other object is resting on the right) or identity featural differences (e.g., one object is a large yellow ball with red dots, and the other object is a small green ball with pink stripes) to establish separate representations for the objects. This explains infants' catastrophic failure at standard tasks: Because the OF and PR systems disagree about the number of objects present in the first event and this disagreement cannot be reconciled, no coherent representation of the event can be stored in memory, leaving infants with no expectation about what they will see in the next event.

According to the two-system account, the best way to make sense of infants' successes and failures at standard and modified individuation tasks is thus to understand how the OF and PR systems operate during infancy, what information they each represent, how they exchange information as events unfold, and how these exchanges mature over time.

1.4. The present research

As is hopefully clear from the preceding sections, the two-system account incorporates elements from both the kind and mapping accounts but differs from them in important ways. In the present research, we focused on the competing claims of the kind and two-system accounts about *why* contrastive categorical information is critical for success in a standard task. According to the kind account, when the two objects emerge in alternation in the first event, infants must decide whether they are watching a single object with changing properties or two different objects with stable properties. Being able to assign the two objects to different kinds, either spontaneously or via lexical or functional manipulations, enables infants to select the latter option. Members of a kind share intrinsic, stable properties, often with rich conceptual content, and they cannot spontaneously change kinds. Assigning the objects to different kinds thus enables infants to infer that two objects are present in the first event, leading them to expect two objects in the second event.

According to the two-system account, in contrast, infants do not need to establish a kind representation for an object to understand that it cannot spontaneously change its properties: The PR system's principle of persistence stipulates that all other things being equal, an object will persist as it is, with all of its properties. Thus, during the first event in a standard task, the PR system is able to establish separate representations for the two objects as long as they differ in (a) one or more categorical descriptors or (b) one or more features that have been identified as causally relevant for the event category involved. When the event comes to an end, however, a coherent representation of the event can be stored in memory only if the OF and PR systems agree that two objects are present. Because the OF system relies on categorical information for individuation, access to contrastive descriptors—any types of contrastive descriptors, whether they involve kinds or not—provides the OF system with distinct tags or handles for individuating the two objects, making possible agreement with the PR system about the number of objects present.

The preceding descriptions highlight a clear difference between the kind and two-system accounts. According to the kind account, infants succeed at a standard task only when they can assign the two objects to different kinds with stable, inherent properties. According to the two-system account, however, *any type of contrastive categorical information* should lead to success, by supplying the OF system with distinct tags for the two objects. In line with this analysis, the present research examined whether infants would succeed at a standard-violation task when the categorical descriptors available to the OF system involved *temporary* or *scant* information. We used two different manipulations, one focusing on temporary descriptors (Experiment 1) and one on scant descriptors (Experiment 2).

Experiment 1 built on physical-reasoning findings showing that the PR system assigns categorical, event-specific roles to objects in events (e.g., support, supportee; occluder, occludee; hitter, hittee; for a review, see Lin et al., 2022). To start, 14-month-old infants saw two support events in which two objects from the same basic-level category, two cylinders that differed only in color and pattern, played different roles in relation to a base. In one event, one cylinder was supported by the base, and in the other event, the other cylinder supported the base. Next, the two cylinders emerged in alternation from behind a large screen, which was then lowered to reveal only one of the cylinders. We reasoned that if the OF system (a) retrieved the cylinders' prior event roles as they emerged from behind the screen (e.g., formerly a support, formerly a supportee), and (b) could take advantage of these descriptors to individuate the cylinders, then infants should succeed at the task. Unlike kind descriptors, role-based descriptors often do not refer to objects' inherent, stable properties; rather, they are temporary, ephemeral descriptors that change as objects participate in successive events from different categories (e.g., first a supportee, then an occludee). Positive findings would thus support the two-system account by showing that even temporary categorical descriptors can induce success in a standard task.

Experiment 2 built on object-segregation findings showing that young infants who are unable to parse a display composed of two adjacent objects can succeed at doing so if they are first exposed to a static array of three objects from the same basic-level category as one of the adjacent objects (Dueker et al., 2003; Needham & Baillargeon, 2000; Needham et al., 2005). Xu and Carey (2000) argued that static arrays are too limited to result in kind representations, as they provide no lexical, functional, or other information to anchor such representations. Static arrays can result only in “perceptual categories determined by properties” (p. 293) or in “experientially derived shape representations [that] contribute to object individuation at very early stages of perceptual processing” (p. 295). Array-based representations may thus induce success in simple segregation tasks but not in more challenging standard individuation tasks, where kind representations are required. To evaluate these claims, Experiment 2 tested 9-month-old infants with a standard task using two objects from different basic-level categories, which infants this age do not yet spontaneously encode (e.g., a block and a cylinder). Infants first saw two static arrays, one per category, composed of three similarly shaped objects (e.g., three different blocks in one trial, three different cylinders in another trial). Next, the middle objects from the two arrays emerged in alternation from behind a large screen, which was then lowered to reveal only one of the objects. We reasoned that if (a) infants were able to form a categorical representation, however scant or shallow, of each array (e.g., block-shaped objects, cylinder-shaped objects) and (b) the OF system could use these array-based descriptors to individuate the two objects as they emerged from behind the screen, then infants should succeed at the task. Here again, positive findings would support the two-system account by showing that even scant categorical descriptors can induce success in a standard task.

In sum, the present research tested infants with a standard-violation task using two novel types of categorical descriptors for the objects shown in the first event: temporary, role-based descriptors derived from the objects’ causal roles in preceding events, and scant, array-based descriptors derived from the objects’ prior inclusion in static arrays of similarly shaped objects. Across experiments, we tested 14-month-olds using two objects from the same basic-level category, as in Xu et al. (2004), and 9-month-olds using two objects from different basic-level categories, as in Xu and Carey (1996); this made for a richer investigation, with different ages and different standard tasks infants typically fail at these ages. Success in each task would support the two-system account's claim that the OF system will use any type of contrastive categorical information at its disposal to individuate objects. Such an eclectic approach could only be advantageous for a cognitive system that depends on categorical information to individuate objects: The more types of categorical information it can recruit, the better its performance overall.

2. Experiment 1

In Experiment 1, we asked whether 14-month-old infants would succeed at a standard-violation task involving two objects from the same basic-level category if these objects first played distinct roles in support events. This experiment built on prior evidence that event roles are crucial to infants' physical reasoning and are represented categorically (Lin et al., 2022). First, recall that each event category refers to a type of causal interaction between objects; infants acquire rules for each category that identify relevant features for predicting outcomes, and these rules are specified in terms of the roles the objects play in the interaction (e.g., when a supportee is released on a support…), ensuring the broad application of the rules to all events from the category (Baillargeon & DeJong, 2017; Wang & Baillargeon, 2008; Wang & Kohne, 2007). For ease of description, we refer to these roles interchangeably as event roles or causal roles. Second, recall that when infants attend to an interaction between objects, the PR system categorizes the event, assigns causal roles to the objects, and then—in line with the rules previously acquired for the category—gathers information about role-relevant features of the objects and their arrangements (e.g., information about the proportion of the supportee's bottom surface that lies on the support; Baillargeon et al., 1992; Hespos & Baillargeon, 2008; Luo et al., 2009; Wang et al., 2016). Given this evidence, it seemed plausible that infants might succeed at a standard task involving two objects from the same basic-level category if the OF system included information in the objects' files about their distinct causal roles in preceding support events (e.g., formerly a support, formerly a supportee).

2.1. Design

Infants were randomly assigned to an experimental or a control condition. They sat on a parent's lap facing a puppet-stage apparatus and received two introduction trials and one test trial. Only the introduction trials differed between conditions (see Figure 2). In the *experimental* condition, these trials depicted two different support events (in counterbalanced order) and involved a base as well as two cylinders that were identical except for color and pattern: One was orange and decorated with red and green fabric horizontal stripes (striped cylinder), and the other was dark blue and decorated with multicolored metallic stars (starred cylinder). Each trial was computer-controlled and lasted 18 s. To start, an experimenter's hand rested on the ledge of a short wide window centered in the back wall of the apparatus. In one trial, the base was centered in front of the window, with one of the cylinders (counterbalanced) to its left (from infants' perspective). The hand lifted the cylinder, placed it on the base, released it, and paused; this 6-s sequence was repeated three times and then the trial ended, with the cylinder on the base. The other trial was similar except that it involved the other cylinder, the positions of the cylinder and the base were reversed, and the hand now deposited the base on the cylinder. For half of the infants (*different-bases* group), two different bases were used across trials (in counterbalanced order): One was light blue and rectangular and the other was wood-patterned and star-shaped. For the other infants (*same-base* group), the same base (counterbalanced) was used in both trials. Because in each group the two cylinders played *distinct causal roles*, we expected both groups to respond similarly to the events they were shown. Testing infants in the two groups presented two possible advantages. First, it made for greater experimental variation in the testing of our hypothesis. Second, including the same-base group helped rule out the possibility that infants in the different-bases group might perceive the two cylinders as distinct not because of their different event roles but simply because of their associations with different bases.

The *control* condition was similar to the experimental condition except that the cylinders no longer played distinct causal roles in the introduction trials. This was achieved differently in the two groups. In the different-bases group, the two cylinders no longer served distinct causal roles: Instead, they now served the *same causal role*, either that of supportee or that of support (counterbalanced). When each cylinder acted as a supportee, the base was centered in front of the window at the start of each trial, with the cylinder to its left; when each cylinder acted as support, it was centered in front of the window, with the base to its left. As before, which cylinder and base were shown first was counterbalanced. In the same-base group, the cylinders played *no causal role* in that they no longer interacted with the base: In one trial, the cylinder was slid forward and backward next to the base, and in the other trial, the base was slid forward and backward next to the cylinder. Infants thus no longer saw support events or any causal interaction between the cylinder and the base, who never came into contact with each other (for other studies using control non-causal events, see Wang & Baillargeon, 2005; Wang & Goldman, 2016; Wang & Onishi, 2017). Which cylinder was shown first, which base was used, and whether the cylinder or the base was moved first were counterbalanced. Because in each group the two cylinders now had *no distinct causal roles*, infants in the two groups were expected to respond similarly to the events they were shown.

Following the two introduction trials, all infants received either a different-objects or a same-object test trial (see Figure 3) adapted from Wilcox and Baillargeon (1998a). Each test trial had a 36-s computer-controlled initial phase, in which the events appropriate for the trial were presented, followed by an infant-controlled final phase (see procedure for the criteria used to end the trial). At the start of the initial phase in the *different-objects* trial, a large blue screen stood upright, centered on the apparatus floor; the screen hid the window in the back wall from infants' view. To start, the experimenter's hand brought out one cylinder (e.g., the starred cylinder) to the right of the screen, gently tapped it on the apparatus floor four times, and then returned it behind the screen; next, the hand performed the same actions with the other cylinder (e.g., the striped cylinder) to the left of the screen. This entire sequence lasted about 18 s and was repeated a second time so that there were four emergences in total, two per cylinder. Next, the screen was lowered to reveal the hand holding the last cylinder to be returned behind the screen—the other cylinder was absent. During the final phase of the trial, the hand gently tilted the cylinder right and left until the trial ended. The *same-object* trial was similar except that the same cylinder was shown on both sides of the screen (in actuality, two identical cylinders were used, to equate the experimenter's actions across the different-objects and same-object trials). In each trial, which cylinder was revealed when the screen was lowered and whether this cylinder was the one from the first or the second introduction trial were counterbalanced.

In line with the two-system account, we predicted that infants in the experimental condition would respond differently in the same-object and different-objects test trials. In the same-object trial, infants should not be surprised to see a single object when the screen was lowered, as there was no basis to expect a different outcome. In the different-objects test trial, however, the situation differed: If, as the two cylinders emerged from behind the screen, the OF system was able to retrieve and use their contrastive prior causal roles to individuate them, then (a) the OF and PR systems should agree that two objects were present behind the screen; (b) at the end of the occlusion event, a coherent representation of the event should be stored in memory; and (c) infants should expect to see two objects when the screen was lowered. Infants should therefore be surprised to see only one object, leading them to look significantly longer in the different-objects as opposed to the same-object trial (for an overview of the violation-of-expectation paradigm, see Margoni et al., in press).

In the control condition, in contrast, we predicted that infants would respond similarly in the same-object and different-objects test trials. In the same-object trial, infants should not be surprised to see a single object when the screen was lowered, as there was no basis to expect a different outcome. In the different-objects trial, the OF system should have no contrastive categorical basis for individuating the two cylinders, as they served either the same causal role (different-bases group) or no causal role (same-base group) in the introduction trials. Consequently, (a) the OF system (one object) and the PR system (two objects) should disagree about how many objects were behind the screen (recall that at 14 months the PR system would be able to individuate the two cylinders based on their different patterns and colors; Lin et al., 2021; Wilcox, 1999); (b) when the occlusion event ended, no coherent representation of the event should be placed in memory; and (c) infants should have no expectation about what they would see when the screen was lowered, in line with the catastrophic failure typically found in standard tasks using objects infants encode as merely featurally distinct. Infants should thus look about equally in the different-objects and same-object trials.

In sum, we predicted that infants in the two conditions would show significantly different looking patterns: longer looking in the different-objects than in the same-object test trial in the experimental condition, but equal looking in the two trials in the control condition. Such results would demonstrate, for the first time, that infants succeed at a standard task using two objects from the same basic-level category when the OF system can take advantage of temporary role-based descriptors from prior events (e.g., formerly a support, formerly a supportee) to individuate the objects. Such a finding would provide evidence for the two-system account's claim that any type of contrastive categorical information can lead to success at a standard task.

2.2. Method

2.2.1. Power analysis

To address our primary research question in Experiment 1, the test-trial data needed to be analyzed using a 2 (Condition) × 2 (Trial) between-subjects ANOVA. To estimate what would be the appropriate sample size for our experiment, we relied on a prior report investigating predictions of the two-system account about experimental manipulations targeting featural properties not yet identified by the PR system (Lin et al., 2021). This report included three experiments with 7- to 13-month-olds whose test-trial data were analyzed using 2 (Condition) × 2 (Trial) between-subjects ANOVAs, each with a sample of 32 infants. These ANOVAS yielded Condition × Trial effect sizes (η_p^2) ranging from .154 to .229. A G*Power analysis (Version 3.1, Faul et al., 2007) based on the lowest of these values, with alpha set at .05 and power set at .95, suggested that the minimum total sample size in our experiment was 74, or about 19 infants for each Condition × Trial cell. For better counterbalancing, our sample included 96 infants, with 24 per cell.

2.2.2. Participants

Participants were 96 healthy term 14-month-olds (49 female, *M* = 13 months, 26 days, range = 12 months, 1 day to 15 months, 22 days). Half of the infants were randomly assigned to the experimental condition and half to the control condition; within each condition, half of the infants received the different-objects test trial and half received the same-object test trial, yielding four Condition × Trial cells of 24 infants each. About half of the infants in each of these cells saw different bases in the two introduction trials (different-bases group), and the other infants saw the same base in both trials (same-base group); similar results were expected for the two groups. Finally, another 4 infants were tested but their data were excluded because they were fussy (2) or distracted (2).

In this and the following experiment, infants' names were obtained from a university-maintained database of parents interested in participating in child development research. Each infant's parent gave written informed consent prior to the testing session, and the protocol was approved by the Institutional Review Board at the University of Illinois at Urbana-Champaign.

2.2.3. Apparatus and stimuli

The apparatus consisted of a brightly lit display booth (106 cm high × 101 cm wide × 59 cm deep) mounted 76 cm above the floor of the testing room. The infant faced a large opening (54 cm × 95 cm) in the front of the apparatus; between trials, a curtain (61 cm × 100 cm) was lowered by a supervisor to hide this opening. Inside the apparatus, the side walls were painted white, and the back wall and the floor were covered with patterned adhesive paper. The window centered in the back wall was 15 cm tall and 45 cm wide; it was located 20 cm above the floor, and its top 12.5 cm were filled with cloth. The primary experimenter wore a white shirt and introduced her right hand and arm into the apparatus through the window. Below the window, a cloth fringe 19 cm tall covered the entire lower portion of the back wall; this fringe served to hide a trapdoor, centered beneath the window, which was used by a secondary experimenter to surreptitiously remove the penultimate cylinder to be returned behind the screen in the test trial.

Four cylinders, each 15.5 cm tall and 10 cm wide, were used in the experiment. There were two identical striped cylinders and two identical starred cylinders. Each cylinder had matching-color felt on its bottom to help muffle sounds when it was tapped against the apparatus floor. The light blue rectangular base was 5.5 cm tall, 11.5 cm wide, and 15 cm deep; the wood-patterned star-shaped base had 5 points and was 8 cm tall and 19 cm wide and deep (largest dimensions). The blue screen used in the test trial was 35 cm tall, 39 cm wide, and 0.25 cm thick; it was centered on the apparatus floor, 26 cm from the back wall. When upright, the screen hid the window in the back wall; this concealed the primary experimenter's actions behind the screen and avoided providing visual cues, when she released one cylinder and grasped the other, as to how many cylinders were present. The screen also concealed the secondary experimenter's actions as she used the trapdoor. A strip of blue felt at the bottom of the screen helped ensure that infants could not detect any movements or light changes behind the screen when in its upright position. The screen was mounted on a long wooden rod (1 cm × 107 cm) that lay across the apparatus floor; its left end was anchored to the left wall, and its right end protruded through a small hole in the right wall. After each object had emerged twice from behind the screen, a hidden tertiary experimenter rotated the right end of the rod to lower the screen. Floor-to-ceiling white curtains surrounded the apparatus and experimenters and hid the testing room from the infants.

During each testing session, a metronome beat softly to help the assistants adhere to the trials' second-by-second scripts. One camera captured an image of the trials, and another camera captured an image of the infant. The two images were combined, projected onto a monitor located behind the apparatus, and watched by the supervisor to confirm that the trials followed the prescribed scripts. Recorded sessions were also checked off-line for accuracy.

2.2.4. Procedure

Each infant sat on a parent's lap centered in front of the apparatus. Parents were instructed to remain silent and neutral and to close their eyes during the test trial. Two naive observers monitored the infant's looking behavior through peepholes in large cloth-covered frames on either side of the apparatus; looking times were computed using the primary observer's responses.

Infants were highly attentive during the two introduction trials and looked, on average, for 94% of each trial. In the test trial, looking times during the initial and final phases were computed separately. Infants were highly attentive during the initial phase and looked, on average, for 93% of the phase. The final phase ended when the infant either (a) looked away for 1 consecutive second after having looked for at least 8 cumulative seconds or (b) looked for 40 cumulative seconds. The 8-s minimum value gave infants additional time to process the scene that was revealed when the screen was lowered, before the trial could end. On average, infants took 8.70 s to cumulate the 8-s minimum for the trial. Interobserver agreement during the final phase of the test trial was calculated by dividing the number of 100-ms intervals in which the two observers agreed by the total number of intervals in the final phase. Agreement was measured for 89/96 infants (only one observer was present for 7 infants) and averaged 95% per infant.

To reduce any positive skewness in the test data, looking times were log-transformed in the analyses (Csibra et al., 2016); for ease of communication, raw looking times are provided in the article. Preliminary analyses of the test data revealed no significant interaction of Condition and Trial with infants' sex, $F(1, 88) = 0.14$, $p = .708$, $\eta^2_p = 0.002$, or with the cylinder revealed at the end of the test trial, $F(1, 88) = 0.00$, $p = .993$, $\eta^2_p = 0.000$. The data were therefore collapsed across these latter two factors in subsequent analyses. A dataset containing the raw data from Experiments 1 and 2 is available at: https://osf.io/7wrsf/.

2.3. Results

Looking times in the final phase of the test trial were analyzed using a 2 × 2 ANOVA with Condition (experimental, control) and Trial (different-objects, same-object) as between-subjects factors. The analysis yielded no main effect of Condition, $F(1, 92) = 0.07$, $p = .786$, $\eta^2_p < 0.001$, no main effect of Trial, $F(1, 92) = 3.70$, $p = .058$, $\eta^2_p = 0.039$, and a significant Condition × Trial interaction, $F(1, 92) = 10.15$, $p = .002$, $\eta^2_p = 0.099$. Planned comparisons indicated that, as expected, infants in the experimental condition (see Figure 4a) looked significantly longer in the different-objects ($M = 24.15$, $SD = 10.12$) as opposed to the same-object ($M = 14.79$, $SD = 6.11$) trial, $F(1, 92) = 13.05$, $p < .001$, *Cohen's d* = 1.05, whereas infants in the control condition (see Figure 4c) looked about equally at the different-objects ($M = 18.38$, $SD = 8.26$) and same-object ($M = 21.52$, $SD = 10.80$) trials, $F(1, 92) = 0.80$, $p = .375$, $d = -0.28$. Nonparametric Wilcoxon rank-sum tests confirmed the results of the experimental ($Z = 3.33$, $p < .001$) and control ($Z = -0.83$, $p = .409$) conditions.

A secondary prediction was that, within each condition, infants in the different-bases and same-base groups would respond similarly. To examine this prediction, for each condition, we conducted a 2 × 2 ANOVA with Group (different-bases, same-base) and Trial (different-objects, same-object) as between-subjects factors. In the experimental condition (see Figure 4b), the ANOVA yielded only a significant main effect of Trial, $F(1, 44) = 14.32$, $p < .001$, $\eta^2_p = 0.246$; neither the main effect of Group, $F(1, 44) = 0.02$, $p = .880$, $\eta^2_p < 0.001$, nor the Group × Trial interaction, $F(1, 44) = 0.03$, $p = .856$, $\eta^2_p < 0.001$, was significant. Planned comparisons revealed that infants in the different-bases group looked significantly longer in the different-objects ($M = 25.23$, $SD = 12.37$) as opposed to the same-object ($M = 14.37$, $SD = 6.05$) trial, $F(1, 44) = 7.86$, $p = .008$, $d = 0.98$, as did infants in the same-base group, $F(1, 44) = 6.48$, $p = .015$, $d = 1.14$ (different-objects: $M = 23.08$, $SD = 7.65$; same-object: $M = 15.22$, $SD = 6.41$). Wilcoxon rank-sum tests confirmed the results of the different-bases ($Z = 2.08$, $p = .038$) and same-base ($Z = 2.34$, $p = .019$) groups. In the control condition (see Figure 4d), the ANOVA yielded no significant effects: Group: $F(1, 44) = 0.10$, $p = .750$, $\eta^2_p = 0.002$; Trial: $F(1, 44) = 0.66$, $p = .419$, $\eta^2_p = 0.015$; Group × Trial: $F(1, 44) = 0.03$, $p = .873$, $\eta^2_p < 0.001$. Planned comparisons revealed that infants in the different-bases group looked about equally at the different-objects (*M* = 17.68, *SD* = 7.64) and same-object (*M* = 20.73, *SD* = 9.75) trials, $F(1, 44) = 0.46$, $p = .503$, $d = -0.30$, as did infants in the same-base group, $F(1, 44) = 0.22$, $p = .639$, $d = -0.18$ (different-objects: *M* = 19.08, *SD* = 9.12; same-object: *M* = 22.19, *SD* = 11.97). Wilcoxon rank-sum tests confirmed the results of the different-bases ($Z = -0.71$, $p = .479$) and same-base ($Z = -0.35$, $p = .724$) groups.

2.4. Discussion

Infants in the experimental condition looked significantly longer if they received the different-objects as opposed to the same-object test trial, and this effect was found in both the different-bases and same-base groups. This positive result suggests that as the two cylinders emerged from behind the screen in the different-objects trial, the OF system retrieved their prior causal roles (e.g., formerly a support, formerly a supportee) and used them to individuate the cylinders. As a result, (a) the OF and PR systems agreed that two cylinders were present behind the screen; (b) when the occlusion event ended, a coherent representation of the event was placed in memory; and (c) infants expected to see two cylinders when the screen was lowered and were surprised see only one instead.

In contrast, infants in the control condition looked about equally in the different-objects and same-object test trials, and this effect was again found in both the different-bases and same-base groups. This negative result suggests that when the two cylinders played no distinct causal roles in the introduction trials—either because they played the same causal role in both trials (different-bases group) or because they played no causal role in either trial (same-base group)—, the OF system had no basis for individuating them in the different-objects trial. Consequently, (a) the OF system assumed that a single cylinder was present behind the screen, whereas the PR system assumed (based on the cylinders' featural differences) that two cylinders were present; (b) this disagreement meant that when the occlusion event came to an end, no coherent representation of the event could be placed in memory; and (c) infants had no expectation about what they would see when the screen was lowered, and they showed little or no surprise when a single cylinder was revealed.

The positive result of the experimental condition demonstrates, for the first time, that the OF system can use temporary role-based categorical descriptors to individuate objects. This result supports the two-system account's claim that infants are not limited to using kind descriptors for individuating objects: Even role-based descriptors can provide the OF system with appropriate tags or handles for individuating objects. It might be suggested that objects' roles in physical events are akin to functions, and that from this perspective another interpretation of our results might be that they extend the range of functional information (a particular type of categorical information) that the OF system can use to categorize objects. However, in prior studies that used functional demonstrations to enhance infants' individuation performance, these demonstrations always reflected objects' specific physical properties: Mashers mashed, tongs picked up, knives cut, markers drew, radios played, lights flashed, rattles filled with bells jingled, and so on (Brower & Wilcox, 2012; Futó et al., 2010; Stavans & Baillargeon, 2018). In the introduction trials of the experimental condition, however, either cylinder could serve the role of supportee or support; what distinguished each cylinder was not its inherent function, tied to its specific properties, but rather the specific way it interacted with the base at the time—its particular role in their causal interaction.

Finally, the negative result of the control condition confirms the negative results of Xu et al. (2004) and extends them from 12- to 14-month-olds. When considered together, there is a striking contrast between the findings that (a) infants as young as 4 months succeed at a standard task when tested with objects they are induced to encode as categorically distinct (Stavans &

Baillargeon, 2018) but (b) infants as old as 14 months fail with objects they encode as merely featurally distinct. This contrast is in line with the two-system account and its focus on how the OF and PR systems each individuate objects, how they interact during and between events, and how irreconcilable disagreements between them result in catastrophic failures.

3. Experiment 2

In Experiment 2, we asked whether 9-month-old infants would succeed at a standard-violation task involving two objects from different basic-level categories (e.g., a block and a cylinder) if they first saw the objects embedded in two static arrays, one per category, composed of three similarly shaped objects from the category (e.g., three different blocks, three different cylinders; recall that infants this age do not yet spontaneously encode a single object's basic-level category). This minimal manipulation, without any lexical, pedagogical, and/or functional information, was suggested by research on early object segregation conducted by Needham and her colleagues. Initial findings indicated that prior to about 7.5 months, infants were unable to correctly parse an adjacent test display composed of a long curved yellow cylinder lying next to a tall blue rectangular box decorated with white squares: When a gloved hand pulled on the cylinder, infants looked about equally whether the cylinder and the block moved together (move-together event) or the cylinder moved apart from the block (move-apart event; Needham, 1998, 2001). Needham asked whether 4.5-month-olds might succeed at parsing this test display if they were first induced to form a block category (Dueker et al., 2003; Needham et al., 2005). In an introduction trial, infants saw a static array of three blocks that differed from the test block only in color and pattern (e.g., blue with red squares, green with right triangles, and purple with white squares). Following exposure to this array, infants looked significantly longer if shown the move-together as opposed to the move-apart event, suggesting that they (a) formed a block category during the introduction trial, (b) viewed the test block as a novel within-category exemplar, (c) inferred that the cylinder and the block must be separate objects, and hence (d) were surprised in the move-together event when the two objects moved as one unit. These and other results indicated that infants correctly parsed the test display when they were able to form a categorical representation of the introduction blocks, but failed otherwise.

According to the kind account, static arrays should be unable to support success at a standard task: They are too limited to induce kind representations, as they provide no lexical, functional, or other information to anchor such representations. They can result only in "perceptual categories determined by properties" (Xu & Carey, 2000, p. 293) or in "experientially derived shape representations" (p. 295) that are sufficient for success in simple segregation tasks but not in more challenging standard individuation tasks, where kind representations are required. According to the two-system account, however, any type of categorical information, however scant or shallow it may be, can support success at a standard task: Contrastive descriptors are essential only because they provide the OF system with unique tags or handles for the two objects used in the task. From this perspective, exposure to static arrays of objects from two basic-level categories should be sufficient to induce success at a standard task involving an object from each array, provided infants were able to form at least a scant categorical representation of each array (e.g., block-shaped objects, cylinder-shaped objects). Experiment 2 tested this prediction.

3.1. Design

Infants were randomly assigned to an experimental or a control condition. They faced the same puppet-stage apparatus as in Experiment 1 and received two introduction trials, one pretest trial, and one test trial. Only the introduction trials differed between conditions (see Figure 5). In the introduction trials of the *experimental* condition, infants saw a static array of three objects from one category in one trial and a static array of three objects from another category in the other trial; no experimenter was present in the window in the back wall to avoid distracting infants. For half of the infants, the objects were members of familiar, everyday categories (*familiar-objects* group): There were three baby shoes that differed in style and color (*shoe* display) and three cups that differed in size, pattern, and color (*cup* display). For the other infants, the objects were members of categories that might appear relatively more novel (*novel-objects* group): There were three green blocks with varying white patterns (*block* display) and three red cylinders with varying yellow patterns (*cylinder* display). Each introduction trial was infant-controlled (see Procedure for criteria), to give infants ample opportunity to form a categorical representation of each display. Infants in the *control* condition were also assigned to a familiar- or novel-objects group and saw identical displays with one exception: In each group, the middle objects of the two displays were swapped (e.g., the shoe display now consisted of two shoes surrounding a cup, and the cup display consisted of two cups surrounding a shoe). Such mixed arrays seemed unlikely to induce contrastive representations of the two basic-level categories involved. In each condition and group, the order of presentation of the two displays was counterbalanced.

Following the introduction trials, infants received either different-objects pretest and test trials or same-object pretest and test trials (see Figure 6). The *different-objects* pretest trial consisted of a 23-s computer-controlled initial phase followed by an infant-controlled final phase. To start, an experimenter's gloved hand brought out the middle object from one of the introduction trials (e.g., a baby shoe) to the right of the screen, paused briefly, then returned the object behind the screen. Next, the hand repeated these actions on the other side of the screen with the middle object from the other introduction trial (e.g., a cup). This sequence lasted about 11 s and was repeated a second time, ending with a paused scene in which only the upright screen was visible;

infants watched this paused scene during the final phase of the trial. The screen was not lowered because the pretest trial was simply intended to familiarize infants with the main components of the test trial (because infants in Experiment 2 were considerably younger than those in Experiment 1, we suspected that a pretest trial might be important to help infants process the test trial). The *same-object* pretest trial was identical except that the same object was shown on both sides of the screen (as in Experiment 1, two identical objects were used, to equate the experimenter's actions across the different-objects and same-object trials). Finally, the different-objects and same-object test trials were identical to the different-objects and same-object pretest trials, respectively, except that the initial phase was lengthened to 25 s to allow for the lowering of the screen. Infants then saw the hand holding the object that was last returned behind the screen (no other object was present). During the final phase of the trial, the hand gently tilted the object left and right until the trial ended. In the experimental condition pretest and test trials, the second object to emerge (and the one revealed in the final phase of the test trial) was always the middle object from the second introduction trial; in the control condition, where the middle objects were swapped, it was always the middle object from the first introduction trial.

In line with the two-system account, we predicted that infants in the experimental condition would respond differently in the same-object and different-objects test trials. In the same-object trial, infants should not be surprised to see a single object when the screen was lowered, as there was no basis to expect a different outcome. In the different-objects test trial, however, the situation differed: If infants formed at least scant categorical representations of the arrays shown in the introduction trials, and the OF system was able to use these representations to individuate the two objects as they emerged from behind the screen, then (a) the OF and PR systems should agree that two objects were present behind the screen; (b) at the end of the occlusion event, a coherent representation of the event should be stored in memory; and (c) infants should expect to see two objects when the screen was lowered. Infants should therefore be surprised to see only one object, leading them to look significantly longer in the different-objects as opposed to the same-object trial.

In the control condition, in contrast, we predicted that infants would respond similarly in the same-object and different-objects test trials. In the same-object trial, here again, infants should not be surprised to see a single object when the screen was lowered, as there was no basis to expect a different outcome. In the different-objects trial, the OF system should have no contrastive categorical basis for individuating the two objects, as the mixed arrays shown in the introduction trials were unlikely to result in separate representations of the two basic-level categories involved. Consequently, (a) the OF system (one object) and the PR system (two objects) should disagree about how many objects were behind the screen (recall that at 9 months the PR system would be able to individuate the two objects based on their different sizes, shapes, and patterns; Baillargeon & DeVos, 1991; Wang et al., 2004; Wilcox, 1999); (b) when the occlusion event ended, no representation of the event should be placed in memory; and (c) infants should have no expectation about what they would see when the screen was lowered, in line with the catastrophic failure typically found in standard tasks using objects infants encode as merely featurally distinct. Infants should thus look about equally in the different-objects and same-object trials.

Finally, within each condition, infants were expected to respond similarly whether they were tested with familiar or novel objects, as in previous standard tasks (Xu, 2002; Xu & Carey, 1996). For example, Xu (2002) found that with a lexical manipulation, 10-month-olds succeeded when tested with either familiar or novel objects; without such a manipulation, however, infants failed with both types of objects.

In sum, we predicted that infants would show significantly different looking patterns in the two conditions: longer looking in the different-objects than in the same-object test trial in the experimental condition, but equal looking in the two trials in the control condition. Such results would demonstrate, for the first time, that 9-month-old infants can succeed at a standard task using two objects from different basic-level categories when the OF system has at its disposal scant categorical descriptors derived from static arrays of objects from each category (e.g., block-shaped objects, cylinder-shaped objects). This finding would provide further evidence for the two-system account and its claim that any type of contrastive categorical information can lead to success at a standard task.

3.2. Method

3.2.1. Power analysis

The design of Experiment 2 was similar to that of Experiment 1 and also used a sample of 96 infants.

3.2.2. Participants

Participants were 96 healthy term 9-month-olds (48 female, *M* = 9 months, 15 days, range = 9 months, 0 days to 10 months, 3 days). Half of the infants were randomly assigned to the experimental condition and half to the control condition; within each condition, half of the infants received the different-objects test trial and half received the same-object test trial, yielding four Condition × Trial cells of 24 infants each. Finally, half of the infants in each of these cells saw relatively more familiar objects in the two introduction trials (familiar-objects group), and half saw relatively more novel objects (novel-objects group); similar results were expected for the two groups. An additional 41 infants were tested but their data were excluded. Of these, 29 (16 in the experimental condition and 13 in the control condition) reached the maximum looking time allowed in the test trial (40 s); for these infants, a single pretest trial might have been insufficient to familiarize them with the components of the test trial. The remaining 12 infants were excluded because they were fussy (8), distracted (2), or drowsy (1), or because the observers had difficulty detecting the direction of the infant's gaze (1).

3.2.3. Apparatus and stimuli

The apparatus and stimuli were the same as in Experiment 1 with two changes. First, the primary experimenter wore a yellow rubber glove on her right hand. Second, different objects were used. In the introduction trials of the familiar-objects group in the experimental condition, infants saw three shoes and three cups, all commercially purchased. The shoes (which varied in size and were 7.5 cm × 7 cm × 14 cm at the largest points) were baby shoes with a strap; the left shoe was made of maroon leather with a brown interior, the middle shoe was made of red patent leather with a white interior, and the right shoe was made of black suede with a white interior. The cups (which varied in size and were 12.5 cm × 8.5 cm at the largest points) were made of plastic; the left cup was clear with a large sunflower at the front and back, the middle cup was bright yellow, and the right cup was pink with blue dots. Identical copies of the middle objects from the two arrays (red shoe, yellow cup) were also available for use in the same-object pretest and test trials. In the control condition, the two middle objects were swapped. In the introduction trials of the novel-objects group in the experimental condition, infants saw three rectangular blocks and three cylinders, all constructed for the experiment. The blocks (each 10 cm × 10 cm × 5 cm) were green and decorated with a varying white pattern; the left block was decorated with small, thin, vertical white strips, the middle block with white flowers of differing sizes, and the right block with white triangles of differing sizes and shapes. The cylinders (each 9.5 cm × 6.5 cm in diameter) were red and decorated with a varying yellow pattern; the left cylinder was decorated with small yellow squares, the middle cylinder with large yellow circles, and the right cylinder with large yellow stars. Here again, identical copies of the middle objects from the two arrays (green block with white flowers, red cylinder with yellow circles) were available for use in the same-object pretest and test trials. In the control condition, the middle objects from the two arrays were swapped.

3.2.4. Procedure

The procedure was similar to that of Experiment 1 with the following changes. Infants received two introduction trials, one pretest trial, and one test trial. Each introduction trial ended when infants (a) looked away for 2 consecutive seconds after having looked for at least 5 (familiar-objects group) or 15 (novel-objects group) cumulative seconds or (2) looked for a maximum of 40 seconds. A longer minimum look was used in the novel-objects group because the objects were relatively more novel and differed only in pattern, so that infants might need more time to encode their differences. As expected given these different minimum-look criteria, infants in the novel-objects group (M = 21.69, SD = 5.76) looked significantly longer overall than those in the familiar-objects group (M = 14.19, SD = 6.18) during the introduction trials, $F(1, 94) = 49.62$, $p < .001$, $\eta^2_p = 0.346$.

Infants were highly attentive during the initial phase of the pretest trial and looked, on average, for 94% of the initial phase. The final phase ended when infants (a) looked away for 1 consecutive second after having looked for at least 5 cumulative seconds or (b) looked for a maximum of 40 seconds.

Finally, infants were highly attentive during the initial phase of the test trial and looked, on average, for 92% of the initial phase. The criteria for ending the final test phase were identical to those in Experiment 1. On average, infants took 8.67 s to cumulate the 8-s minimum for the trial. Interobserver agreement during the final phase of the test trial was calculated for 90/96 infants (only one observer was present for the other 6 infants) and averaged 96% per infant.

As In Experiment 1, all analyses were conducted using log-transformed data. Preliminary analyses of the test data revealed no interaction of Condition and Trial with infants' sex, $F(1, 88) = 0.02$, $p = .903$, $\eta^2_p < 0.001$, or with the object revealed at the end of the test trial, $F(1, 88) = 0.00$, $p = .976$, $\eta^2_p = 0.000$; the data were therefore collapsed across the latter two factors in subsequent analyses.

3.3. Results

Pretest trial. Looking times during the final phase of the pretest trial were analyzed using a 2 × 2 ANOVA with Condition (experimental, control) and Trial (different-objects, same-object) as between-subjects factors. The Condition × Trial interaction was not significant, $F(1, 92) = 1.70$, $p = .196$, $\eta^2_p = 0.018$, nor were the main effects of Condition, $F(1, 92) = 0.02$, $p = .894$, $\eta^2_p < 0.001$, and Trial, $F(1, 92) = 1.14$, $p = .288$, $\eta^2_p = 0.012$. Thus, as expected, infants in each condition tended to look equally at the upright screen during the final phases of the different-objects and same-object pretest trials (for the means of each Condition × Trial cell, see the dataset at: https://osf.io/7wrsf/).

Test trial. Looking times during the final phase of the test trial were analyzed as in the pretest trial. The analysis yielded significant main effects of Condition, $F(1, 92) = 8.85$, $p = .004$, $\eta^2_p = 0.088$, and Trial, $F(1, 92) = 7.95$, $p = .006$, $\eta^2_p = 0.080$, as well as a significant Condition × Trial interaction, $F(1, 92) = 8.47$, $p = .005$, $\eta^2_p = 0.084$. Planned comparisons revealed that in the experimental condition (see Figure 7a), infants who received the different-objects trial ($M = 24.43$, $SD = 6.01$) looked significantly longer than those who received the same-object trial ($M = 16.50$, $SD = 5.98$), $F(1, 92) = 16.42$, $p < .001$, $d = 1.31$. In the control condition (see Figure 7c), in contrast, infants who received the different-objects trial ($M = 16.20$, $SD = 5.61$) looked about the same as those who received the same-object trial (*M* = 17.12, *SD* = 8.49), $F(1, 92) = 0.00$, $p = .949$, $d = -0.06$. Wilcoxon rank-sum tests confirmed the results of the experimental ($Z = 3.93$, $p < .001$) and control ($Z = 0.15$, $p = .877$) conditions.

As in Experiment 1, a secondary prediction was that, within each condition, infants in the two groups would respond similarly. To examine this prediction, for each condition, we conducted a 2 × 2 ANOVA with Group (familiar-objects, novel-objects) and Trial (different-objects, same-object) as between-subjects factors. In the experimental condition (see Figure 7b), the ANOVA yielded only a significant main effect of Trial, $F(1, 44) = 20.96$, $p < .001$, $\eta^2_p = 0.323$; the main effect of Group was not significant, $F(1, 44) = 0.05$, $p = .822$, $\eta^2_p = 0.001$, nor was the Group × Trial interaction, $F(1, 44) = 0.03$, $p = .870$, $\eta^2_p < 0.001$. Planned comparisons revealed that infants in the familiar-objects group looked significantly longer in the different-objects (*M* = 24.46, *SD* = 6.09) as opposed to the same-object (*M* = 16.89, *SD* = 6.42) trial, $F(1, 44) = 9.74$, $p = .003$, $d = 1.29$, as did infants in the novel-objects group, $F(1, 44) = 11.25$, $p = .002$, $d = 1.34$ (different-objects: *M* = 24.39, *SD* = 6.19; same-object: *M* = 16.12, *SD* = 5.76). Wilcoxon rank-sum tests confirmed the results of the familiar-objects ($Z = 2.51$, $p = .012$) and novel-objects ($Z = 2.92$, $p = .004$) groups. In the control condition (see Figure 7d), the ANOVA yielded no significant effects: Group: $F(1, 44) = 0.53$, $p = .470$, $\eta^2_p = 0.012$; Trial: $F(1, 44) = 0.00$, $p = .956$, $\eta^2_p < 0.001$; Group × Trial: $F(1, 44) = 0.17$, $p = .685$, $\eta^2_p = 0.004$. Planned comparisons revealed that infants in the familiar-objects group looked about equally in the different-objects (*M* = 15.21, *SD* = 5.79) and same-object (*M* = 16.54, *SD* = 8.21) trials, $F(1, 44) = 0.11$, $p = .744$, $d = -0.17$, as did infants in the novel-objects group, $F(1, 44) = 0.06$, $p = .804$, $d = 0.05$ (different-objects: *M* = 17.18, *SD* = 5.49; same-object: *M* = 17.70, *SD* = 9.09). Wilcoxon rank-sum tests confirmed the results of the familiar-objects ($Z = -0.32$, $p = .751$) and novel-objects ($Z = 0.40$, $p = .686$) groups.

3.4. Discussion

Infants in the experimental condition looked significantly longer in the different-objects than in the same-object test trial, and this effect was found in both the familiar-objects and novel-objects groups. This positive result suggests that infants were able to form at least a scant categorical representation of each array shown in the introduction trials (e.g., block-shaped objects, cylinder-shaped objects). As the middle objects from the two arrays emerged from behind the screen in the different-objects trial, the OF system was able to use these contrastive array-based descriptors to individuate the two objects. As a result, (a) the OF and PR systems agreed that two objects were present behind the screen; (b) when the occlusion event ended, a coherent representation of the event was stored in memory; and (c) infants expected to see two objects when the screen was lowered, and they were surprised to see only one instead.

In contrast, infants in the control condition looked about equally in the different-objects and same-object trials, in both the familiar-objects and novel-objects groups. This negative result suggests that infants were unable to form categorical representations of the mixed arrays shown in the introduction trials; this left the OF system with no basis for assigning distinct categorical descriptors to the two objects in the different-objects trial. Consequently, (a) the OF system assumed that a single object was present behind the screen, whereas the PR system assumed that two objects were present (based on their different sizes and shapes); (b) this disagreement meant that when the occlusion event came to an end, no coherent representation of the event could be placed in memory; and (c) infants had no expectation about what they would see when the screen was lowered, and they showed little or no surprise when a single object was revealed.

The negative result of the control condition confirms prior findings that infants under 12 months do not yet spontaneously encode objects' basic-level categories in standard tasks, even when tested with familiar, everyday objects with distinct functions such as balls, sippy cups, baby bottles, baby shoes, and baby books (Xu, 2002; Xu & Carey, 1996). By contrast, the positive result of the experimental condition provides the first evidence that the OF system can use even scant, shallow categorical descriptors to individuate objects. At 9 months of age, exposure to two different arrays of similarly shaped objects, without any accompanying lexical, pedagogical, and/or functional information, was sufficient to induce success at a standard task using an object from each array. This result supports the two-system account's claim that any types of contrastive categorical descriptors, whether they involve kinds, temporary role-based descriptors, or scant array-based descriptors, can provide the OF system with unique tags or handles for individuating objects.

4. General discussion

Although the kind and two-system accounts agree that categorical information is essential for infants to succeed at a standard task, they disagree about why this information matters. According to the kind account, infants fail when they are uncertain whether the first event involves a single object with changing properties or two distinct objects with stable properties. Being able to assign the objects to different kinds resolves this difficulty, because kinds refer to object categories with intrinsic, stable properties: An object cannot spontaneously change kind. Categorical information, and more specifically kind information, is thus essential because it enables infants to correctly individuate the two objects.

According to the two-system account, in contrast, infants fail at a standard task when the OF and PR systems disagree about how many objects are present: The OF system, which uses categorical information to individuate objects, mistakenly assumes that a single object is present, whereas the PR system, which uses both categorical and featural information, realizes that two distinct objects are present. If this disagreement persists as the event comes to an end, then no coherent representation of the event can be stored in memory, leading infants to have no expectation at all about the next event. In this account, categorical information is thus essential because it provides the OF system with unique tags for individuating the two objects, communicating about them with the PR system, and tracking them from event to event. From this perspective, *any type of categorical information* the OF system can recruit for uniquely tagging the two objects should lead to success. The present research examined this prediction with two types of categorical descriptors not previously used in individuation tasks: *temporary* descriptors derived from the objects' distinct causal roles in preceding events (Experiment 1) and *scant* descriptors suggested by the objects' prior inclusion in static arrays of similarly shaped objects (Experiment 2).

In Experiment 1, in line with prior findings by Xu et al. (2004), 14-month-olds failed at a standard-violation task involving two objects from the same basic-level category. However, infants succeeded if they first received two introduction trials in which the objects played distinct causal roles in support events. In one trial, one object was supported by a base and thus played the role of supportee, and in the other trial, the other object supported a base and thus played the role of support. In Experiment 2, in line with prior findings by Xu and Carey (1996) and follow-up investigations, 9-month-olds failed at a standard-violation task involving two objects from different basic-level categories. However, infants succeeded if they first received two introduction trials in which the objects appeared in different static arrays. One trial showed one object surrounded by two similarly shaped members of its category, and the other trial showed the other object surrounded by two similarly shaped members of its category; neither trial presented any lexical, functional, or pedagogical information to suggest that each array represented a separate category. In each experiment, the OF system was able to recruit the temporary or scant categorical information provided to assign distinct categorical descriptors to the two objects in the occlusion event. As a result, (a) the OF and PR systems agreed that two objects were present behind the screen; (b) when the occlusion event ended, a coherent representation of the event was stored in memory; and (c) infants expected to see two objects when the screen was lowered, so they were surprised to see only one instead.

In each experiment, infants were no longer surprised to see only one object if the introduction trials were modified so that they no longer provided the OF system with contrastive categorical descriptors. In Experiment 1, the objects no longer played distinct causal roles in the introduction trials: They played the same causal role in both trials, or they played no causal role in either trial. In Experiment 2, the introduction trials presented mixed arrays of objects from the two categories, preventing infants from forming a separate representation of each category. In both cases, the OF system no longer had any basis for assigning distinct categorical descriptors to the two objects in the occlusion event. As a result, (a) the OF system assumed that a single object was present behind the screen, whereas the PR system assumed that two objects were present (based on their featural differences); (b) when the occlusion event came to an end, no coherent representation of the event could be placed in memory; and (c) infants had no expectation about what they would see when the screen was lowered, in line with the catastrophic failure typically found in standard-violation tasks when infants encode the two objects as merely featurally distinct.

Together, these results provide evidence that the OF system is able to individuate objects in standard-violation tasks using *temporary* descriptors derived from the objects' distinct causal roles in preceding events as well as *shallow* descriptors suggested by the objects' prior inclusion in static arrays of similarly-shaped objects. As such, the results provide evidence against the kind account's assumption that kind descriptors are necessary for success at standard tasks, and evidence in favor of the two-system account's assumption that *any type of categorical information the OF system can recruit*, however temporary or scant it may be, is sufficient for success. Such an eclectic approach is obviously advantageous for a cognitive system that relies on categorical information to individuate objects: The more types of categorical information it can recruit, the better its performance overall.

4.1. Adult findings

Although our research focuses on the developing interactions of the OF and PR systems in infancy, it finds intriguing echoes in the adult literature. Here, we briefly describe two such echoes. A first one comes from research on event perception (Radvansky & Zacks, 2011; Sargent et al., 2013; Swallow et al., 2009; Zacks, 2010). According to this research, adults who observe a complex dynamic scene (e.g., a gourmet chef giving a class on how to make a chocolate soufflé) spontaneously segment the scene into distinct events (e.g., gather the ingredients, preheat the oven, place the chocolate and coffee in a small pan, and so on), with significant boundaries between successive events. As each new event begins, adults build a representation of the event that draws on incoming perceptual information as well as stored knowledge. This representation captures important aspects of the event and is used to predict how it will unfold. The representation is actively maintained in working memory and is updated as additional information becomes available (provided it does not change the basic nature of the event). As each event ends, its representation is *flushed from working memory and stored*, to make way for the construction of the next event's representation. One way of describing the two-system account's explanation for standard-violation tasks is that it focuses on the storage process italicized above: When the occlusion event comes to an end and the OF and PR systems agree on how many objects are present behind the screen, the event's representation is *successfully flushed from working memory and stored away*; when the two systems disagree, however, this process is halted and no representation is stored, leaving infants with no basis for forming an expectation about what they will see in the next, no-occlusion event.

A second echo comes from research on change blindness which shows that adults often fail to detect changes to attended objects that go briefly out of view, in both laboratory and real-world settings (Archambault et al., 1999; Levin & Simons, 1997; Rensink, 2002; Simons et al., 2002). Several factors may cause adults to overlook such changes, but one that is particularly germane to the present discussion is the following: As they mentally compare the pre- and post-change objects, adults sometimes focus exclusively on the objects' categorical descriptors; if these descriptors remain constant across views, adults mistakenly infer object continuity, despite marked (and registered) differences in the objects' featural properties (Angelone et al., 2003; Hollingworth et al., 2001; Mitroff et al., 2004; Simons & Levin, 1998). In an experiment inspired by the work of Xu and Carey (1996), for example, an occlusion event was embedded in a novel social interaction on a college campus (Simons & Levin, 1998). An actor who carried a map and was dressed as a construction worker (e.g., in a plain hard hat, black shirt, and white pants) approached individual students and asked for directions. In each case, the interaction between the actor and the student was interrupted by two confederates who passed between them, carrying a door. While occluded, the actor surreptitiously switched positions with one of the confederates, another young White man who also carried a map and was dressed as a construction worker, though in different clothing (e.g., a hard hat with a logo, a tool belt, a light blue shirt, and tan pants). Most adults failed to notice the change to the actor, suggesting that they (a) selectively compared the pre- and post-change actors' categorical descriptors (e.g., young, White, male construction worker requesting directions) and

(b) mistakenly inferred object continuity because these descriptors were maintained across views. When watching simple occlusion events such as those in standard-violation tasks, adults would no doubt be able to use any categorical or featural differences between the two objects to individuate them; what this research on change blindness demonstrates, however, is that under more challenging information-processing conditions, adults' OF system, like infants', may rely primarily on categorical information to individuate objects.

4.2. Future directions

4.2.1. Present manipulations

Each of our experimental manipulations raises multiple questions for future research. To start, consider the role-based manipulation from Experiment 1. One might ask whether infants would still succeed: if in the introduction trials the two objects played distinct causal roles in an event category other than support (e.g., hitter vs. hittee); if the two objects participated in events from different categories (e.g., supportee vs. hittee); if only one of the objects played a causal role (e.g., supportee); and if the delay between the introduction and test trials was increased, or pretest trials were used to fill that delay. Finally, moving beyond physical events, one might ask whether infants would also succeed if shown animated characters that played different roles in social events with readily reversible roles such as giver vs. givee, helper vs. helpee, or chaser vs. chasee. We would also expect infants to succeed with social events that revealed differences in the characters' social status (e.g., leader vs. follower; Margoni et al., 2018; Stavans & Baillargeon, 2019), rationality (e.g., efficient vs. inefficient; Csibra et al., 1999, 2003), or moral character (e.g., fair vs. unfair distributor; Meristo & Surian, 2013; Ting & Baillargeon, 2021). Indeed, positive evidence has already been obtained in individuation tasks using two characters who acted as a helper vs. a hinderer (Taborda-Osorio et al., 2019), who demonstrated opposite preferences (Bródy et al., 2022), or who belonged to the same novel group as the infants, based on shared preferences, and were accordingly processed as distinct ingroup individuals (Fogiel et al., 2023).

Turning to the array-based manipulation from Experiment 2, one might ask whether infants would still succeed if the two test objects were not any of the previously-seen objects from the introduction trials but new objects from the categories presented in these trials, as in the work of Needham and her colleagues (Dueker et al., 2003; Needham et al., 2005); if the introduction trials presented narrower object categories that did not involve shape differences (e.g., red cylinders with varied yellow patterns, green cylinders with varied white patterns); if the same object category (e.g., red cylinders with varied yellow patterns) was presented in both introduction trials, so that only one of the two test objects (red cylinder with yellow pattern, green block with white pattern) could be assigned to a basic-level category; and if a longer delay was imposed between the introduction and test trials.

Finally, comparing our two manipulations, infants might be able to withstand longer delays with array-based as opposed to role-based manipulations. Role-based descriptors such as support and supportee come from temporary event representations whose details might quickly fade as new events take place. In contrast, array-based descriptors such as cylinder-shaped and block-shaped objects would seem to reflect more long-term properties and, as such, might be more likely to become a permanent part of the objects' representations. In line with this suggestion, Dueker et al. (2003) found that 5-month-olds still showed a positive effect of exposure to an array of three different blocks when this exposure took place in their homes 72 hours before they were tested in the lab with the adjacent cylinder-and-block display.

Answers to the preceding research questions would help us better understand the nature and scope of our two manipulations and the various cognitive mechanisms that might contribute to them.

4.2.2. Further tests of the two-system account

Other, broader questions for future research focus more directly on the two-system account. In particular, if we are right that access to distinct categorical descriptors for objects provides the OF system with distinct tags for individuating the objects, for communicating about them with the PR system, and for tracking them from event to event, then we should be able to identify other situations in which the lack of distinct categorical descriptors would lead to failure. One such situation involves *position binding*—the binding of objects to their specific left-right positions in a particular location. For example, imagine that in a new study adapted from Experiment 1, 14-month-olds receive test trials in which the striped and starred cylinders first stand side by side at the center of the apparatus. Next, a screen is raised to hide them. After a brief interval of, say, 10 s, the screen is lowered to reveal the two cylinders in either the same left-right positions (expected event) or swapped positions (unexpected event). The two-system account predicts that infants should fail at this task. During the occlusion event, the OF system will assign similar spatiotemporal (behind the screen) and identity (cylinders) categorical descriptors to the two cylinders. When the PR system queries the OF system for featural information about the color and pattern of each cylinder, there will be no way for the OF system to unambiguously provide this information: Without a unique tag or handle for each cylinder, answers to the queries will be ambiguous. As in Experiment 1, however, infants should succeed at the task if they first saw the two cylinders play distinct causal roles in support events, thereby providing the OF and PR systems with clear means of referring uniquely to each cylinder.

Along the same lines, we would also predict difficulties with *feature binding*—the binding of specific featural properties to objects. To see how, imagine that in a new study adapted from

Experiment 2, 9-month-olds receive test trials in which a red cylinder with a yellow pattern and a green block with a white pattern stand side by side at the center of the apparatus. Next, a screen is raised for a brief period and then lowered to reveal the two objects with either the same features as before (expected event) or swapped features (i.e., the red cylinder now has the white pattern and the green block now has the yellow pattern; unexpected event). Here again, we would expect infants to fail at the task. During the occlusion event, the OF system will assign similar categorical descriptors to the two objects; when the PR system queries the OF system for featural information about the size, shape, and pattern of each object, there will be no way for the OF system to unambiguously provide this information, making it impossible for the PR system to bind the information it receives to the correct object. As in Experiment 2, however, infants should succeed at the task if they first received introduction trials depicting separate arrays of cylinders and blocks.

Obtaining the predicted results in these position-binding and feature-binding tasks would provide further support for the two-system account by demonstrating its usefulness in explaining infants' successes and failures in a broad range of cognitive tasks.

4.2.3. Developmental progression

Despite the significant progress that has been made in understanding early individuation over the past 35 years, two key questions remain: At what age do infants finally succeed at standard tasks using objects that are merely featurally distinct, and what are the mechanisms that make this milestone achievement possible?

One possibility is that the OF system eventually becomes capable of recruiting featural information to individuate objects. For example, when an object briefly goes out of view, the OF system could first check whether the object that reappears has the same categorical descriptors as the object that disappeared; if yes, it could then check whether its featural properties are also the same. One developmental mechanism at work might be an increase in infants' information-processing resources: As their working memory expands, infants might become better able to perform these two checks (first descriptors, then features) in quick succession, even under time pressure. Another mechanism might involve the acquisition of adjective labels: Just as the acquisition of basic-level noun labels (duck, ball, shoe) appears to facilitate the OF system's use of basic-level information for individuation purposes, the acquisition of adjective labels (big, dotted, red) might facilitate its use of featural information.

Another possibility is that it is the interaction between the OF and PR systems that develops (perhaps due to brain maturation) and finally allows infants to succeed at standard tasks using objects they encode as merely featurally distinct. To see how such a developmental process might unfold, consider remainder tasks by Wilcox and Schweinle (2002) with infants 4.5, 5.5, and 7.5 months of age. Infants first saw a yellow egg adorned with stars move behind a large screen. Next, a tall rectangular block covered with red-and-white checkered fabric emerged on the other side of the screen and paused in full view. Finally, the screen was lowered to reveal one of three outcomes: (a) no object stood behind the screen; (b) another, identical block stood behind the screen; or (c) an egg stood behind the screen. At 4.5 months, infants did not detect a violation in either (a) or (b), suggesting that they had no particular expectation about what they would see when the screen was lowered. At 5.5 months, infants detected a violation only in (a), suggesting that they expected to see a second object but were uncertain what its features should be. Finally, at 7.5 months, infants detected a violation in both (a) and (b), and they also detected a violation if a triangle moved behind the screen but an egg was revealed. These older infants thus not only expected to see a second object but specifically expected it to be whichever object (egg or triangle) had initially moved behind the screen. One interpretation of these findings, suggested by the two-system account, is as follows. At the end of the occlusion event, the OF and PR systems disagreed about how many objects were present: The OF system assumed that a single object was present, the one visible to the right of the screen, but the PR system signaled that a second object was also present behind the screen (based on the objects' differences in shape, size, and/or pattern). At 7.5 months, the OF system was able to use this signal to open an object file for this second object and to import information about its features. At 5.5 months, the OF system was able to open an object file but could do no more, so infants knew there was a second object but not what it was. Finally, at 4.5 months, the OF system was unable to open a second object file; as a result, the two systems disagreed about how many objects were present, resulting in the catastrophic failure typically observed under such circumstances. Perhaps a similar developmental process might occur, at some point in the second year of life, for standard tasks using two objects that are merely featurally distinct. At first, as we know, the OF system would be unable to use the signal from the PR system (two objects) to open a file for the second object in the hiding location. In time, however, the OF system would become able to open a second file and to import some or all of the featural information from the PR system, leading infants to expect two particular objects in the hiding location.

Whichever of these and other possibilities turns out to be correct, much remains to be uncovered about the nature of the interactions between the OF and PR systems and about the evolution of these interactions over the course of early childhood. It is a developmental story that is only imperfectly understood and remains to be told.

4.3. Conclusion

The present results, together with those reviewed in this article, call for new efforts to understand the nature and operation of the OF and PR systems, to specify the developmental trajectory of each system and the mechanisms responsible for it, and to shed light on how interactions between the two systems mature over time, making possible new cognitive achievements.

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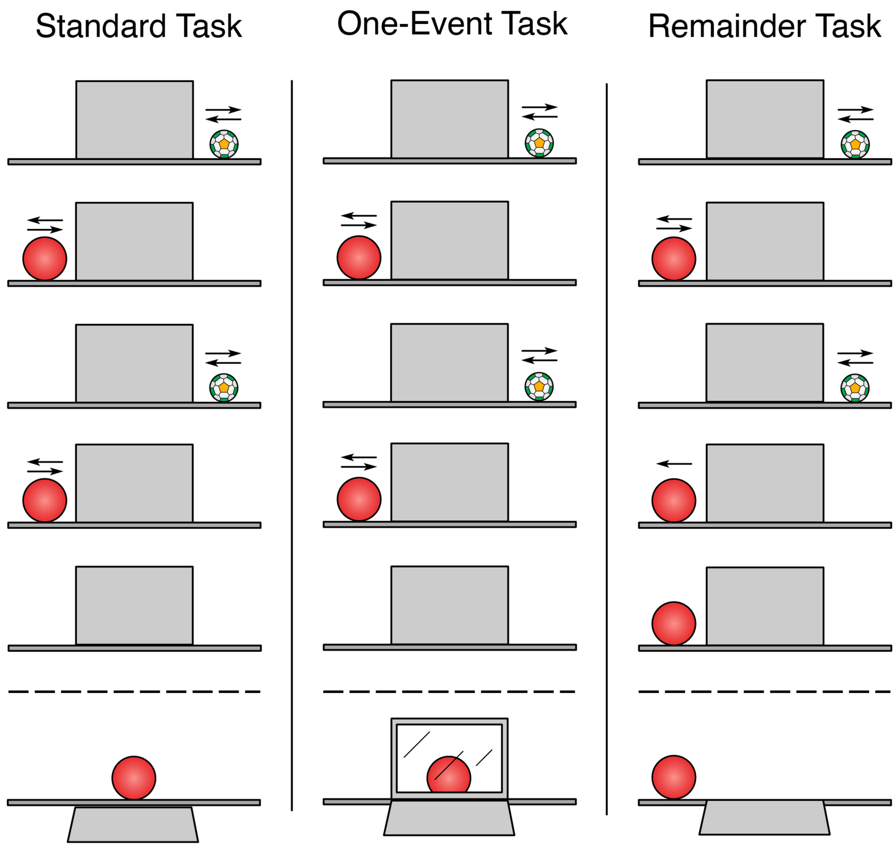

Fig 1. Schematic depiction of individuation violations in standard tasks and two modified tasks. In **standard** tasks, infants see a sequence of two events. In the first (occlusion) event, two different objects emerge in alternation from behind a screen. In the second (no-occlusion) event, the screen is lowered to reveal only one of the objects. In **one-event** tasks, a transparent panel stands behind the screen so that infants see a single, ongoing occlusion event, first with an opaque and then with a transparent occluder. In **remainder** tasks, only one object remains behind the screen at the end of the occlusion event, because the last-seen object is in a different location, such as next to the screen. When the two objects differ only in their featural properties, as depicted here, infants aged 12 months and younger typically fail to detect the violation they are shown in standard tasks, but succeed in one-event and remainder tasks.

Fig. 2. Schematic depiction of the events shown in the two introduction trials of the different-bases and same-base groups in the experimental and control conditions of Experiment 1. In the experimental condition, a cylinder was placed on a base in one trial, and a base was placed on another cylinder in the other trial; the two cylinders thus played distinct causal roles, that of supportee or support. Across trials, infants in the different-bases group saw two different bases, and infants in the same-base group saw the same base. In the control condition, infants in the different-bases group saw both cylinders play the same causal role, either that of supportee (shown here) or support. For infants in the same-base group, neither cylinder played a causal role; in one trial, one cylinder was slid forward and backward next to the base, and in the other trial, the base was slid forward and backward next to the other cylinder.

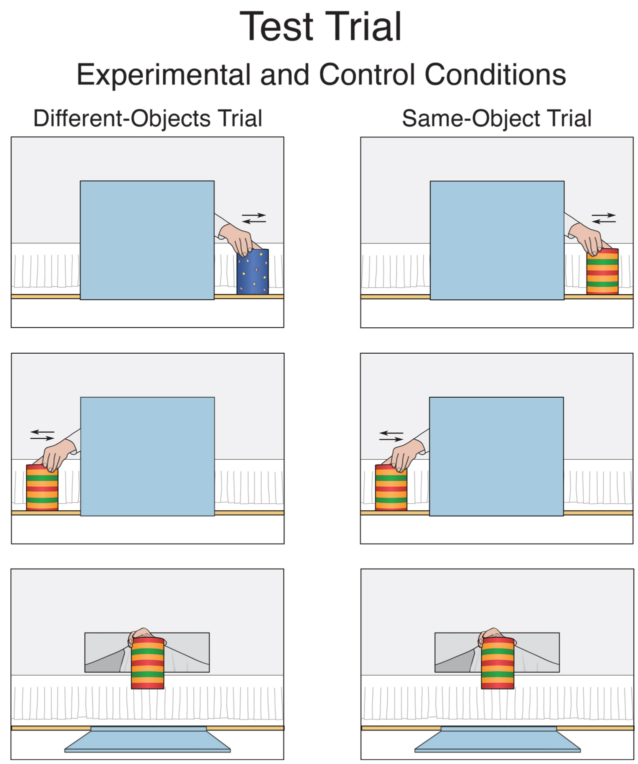

Fig. 3. Schematic depiction of the events shown in the different-objects and same-object test trials of the experimental and control conditions in Experiment 1. In the different-objects trial, the two cylinders from the introduction trials emerged in alternation on either side of an upright screen. This sequence was presented twice, and then the screen was lowered to reveal only the last-seen cylinder. The same-object trial was similar except that the same cylinder emerged on either side of the screen.

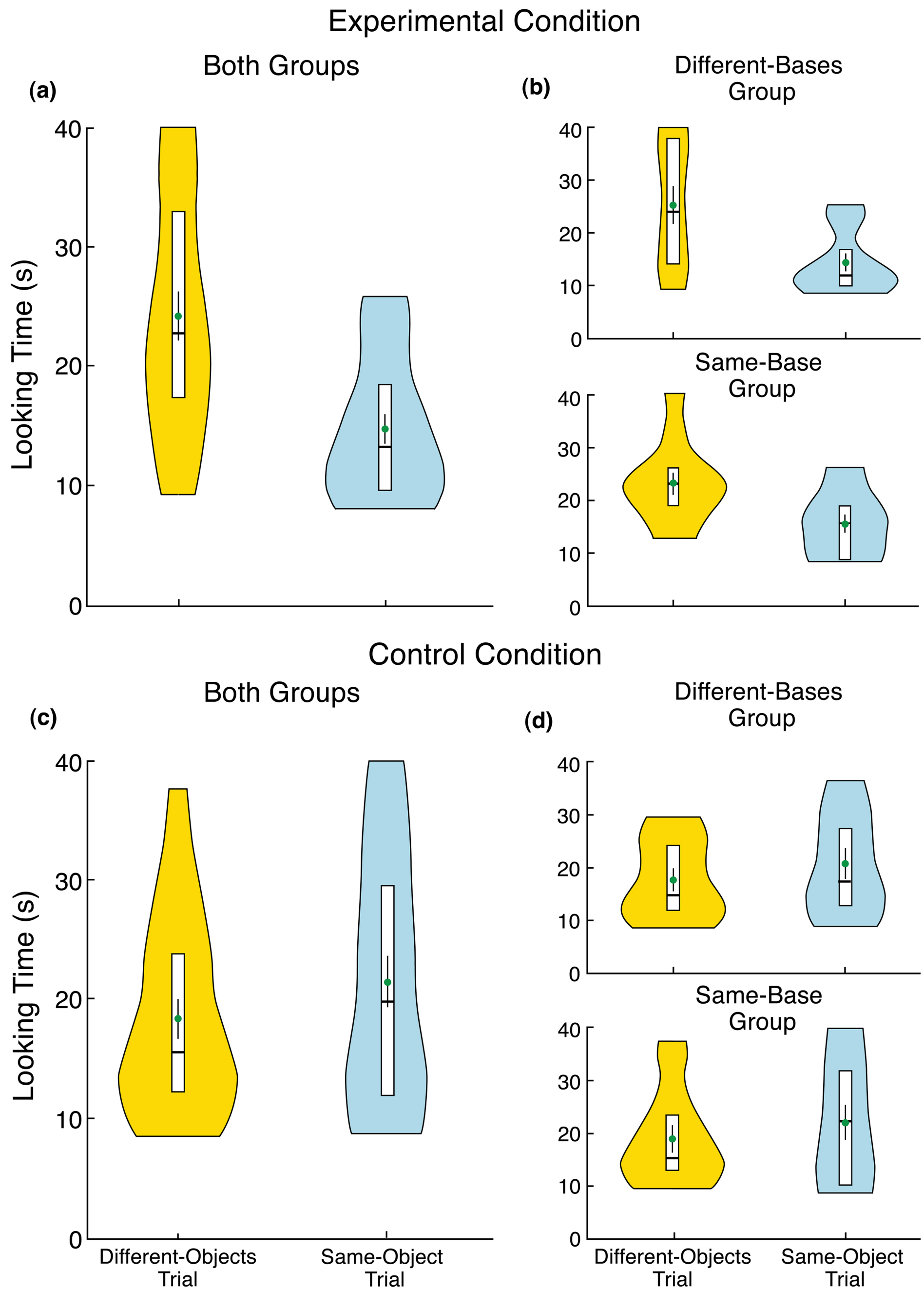

Fig. 4. Violin plots showing infants' raw looking times during the different-objects and same-object test trials in Experiment 1, in the experimental condition (**a**) and its different-bases and same-base groups (**b**), and in the control condition (**c**) and its different-bases and same-base groups (**d**). In each condition, similar results were expected in the two groups. Dots represent means, and error bars represent standard errors. The width of the shaded area represents the proportion of looking times observed at each value, smoothed by a kernel density estimator. Overlaid on each violin plot is a boxplot with a box ranging from the 25th to the 75th percentile, and a line drawn at the median.

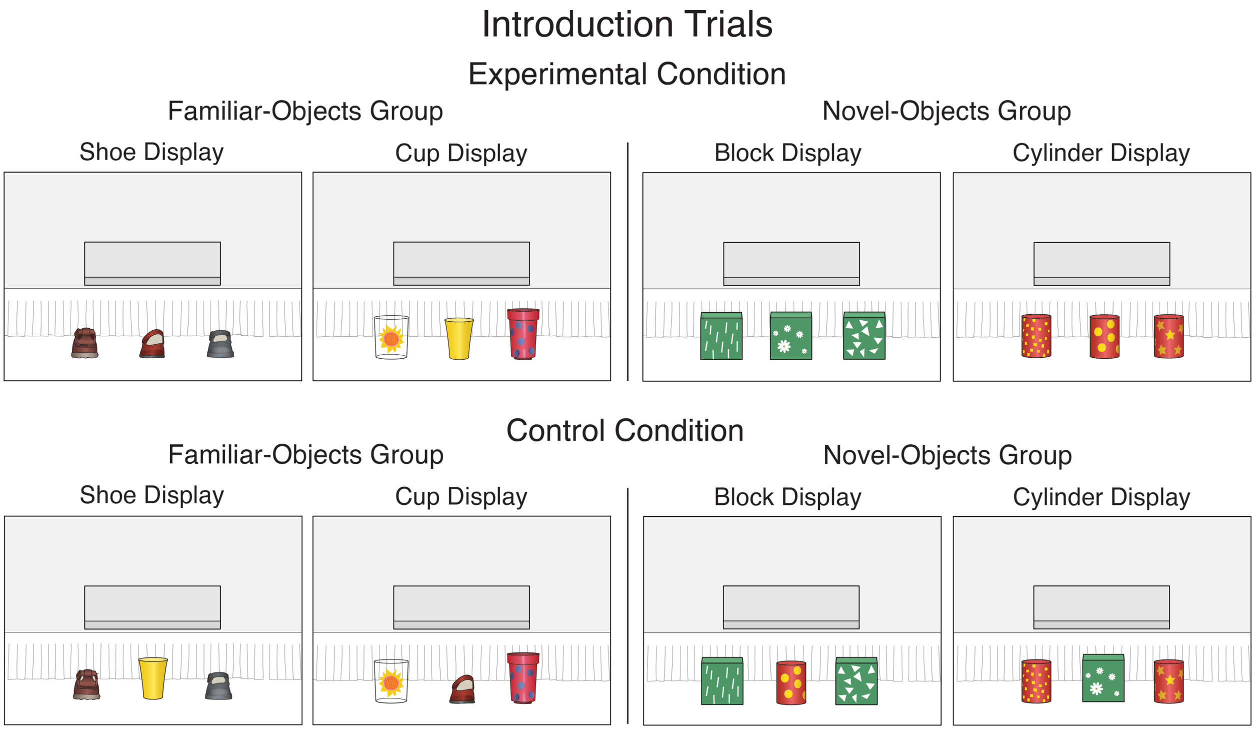

Fig. 5. Schematic depiction of the static displays shown in the two introduction trials of the familiar-objects and novel-objects groups in the experimental and control conditions of Experiment 2. In the experimental condition, infants saw an array of three objects from one category in one trial and an array of three objects from another category in the other trial. Infants in the familiar-objects group saw baby shoes and cups, and infants in the novel-objects group saw blocks and cylinders. The control condition was similar except that in each group the middle objects of the two arrays were swapped.

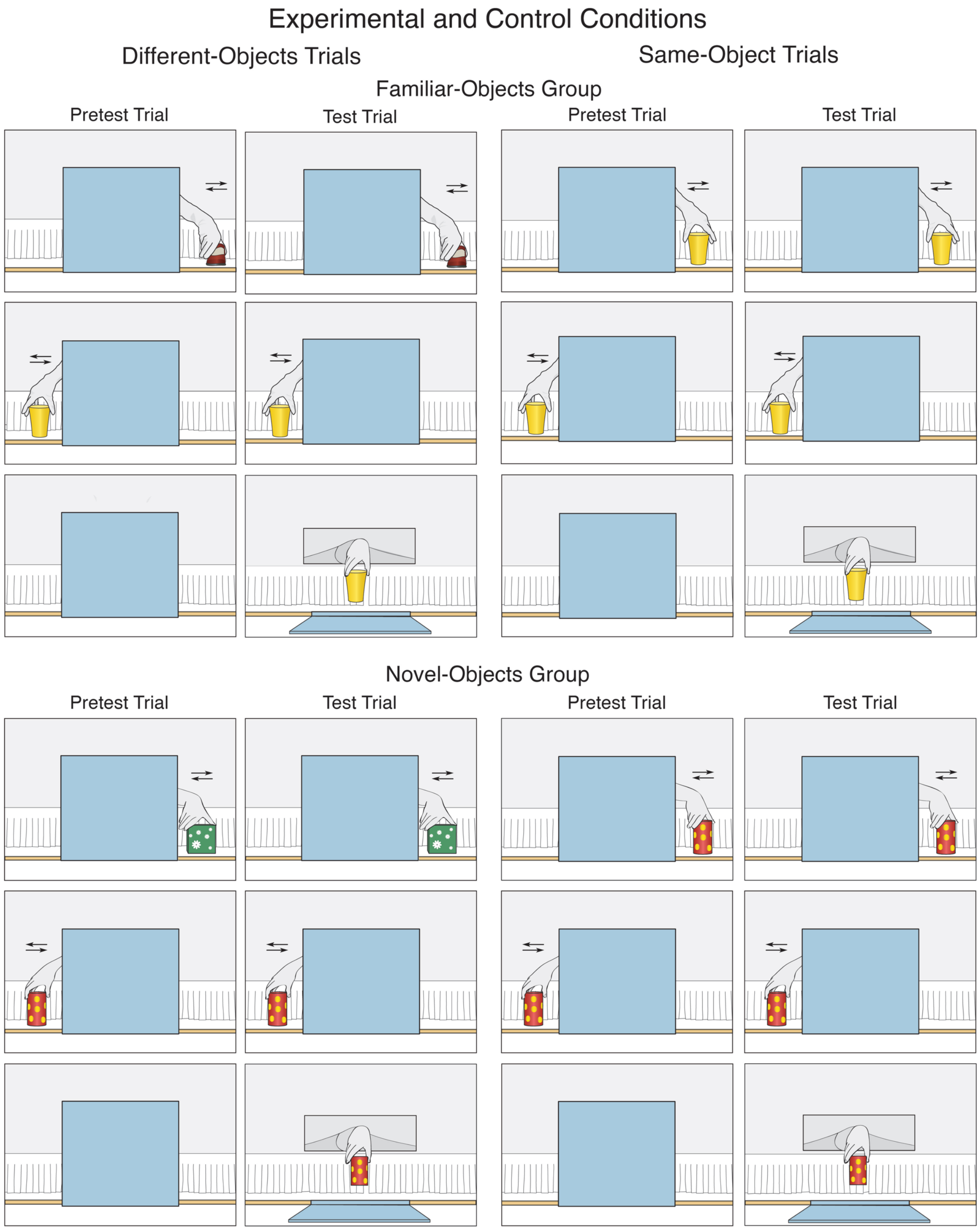

Fig. 6. Schematic depiction of the events shown in the different-objects and same-object pretest and test trials of the familiar-objects and novel-objects groups in the experimental and control conditions of Experiment 2. In the different-objects trials, the middle objects from the two introduction trials emerged in alternation on either side of an upright screen. This sequence was presented twice, and then the screen either remained upright until the end of the trial (pretest trial) or was lowered to reveal only the last-seen object (test trial). The same-object trials were similar except that the same object emerged on either side of the screen.

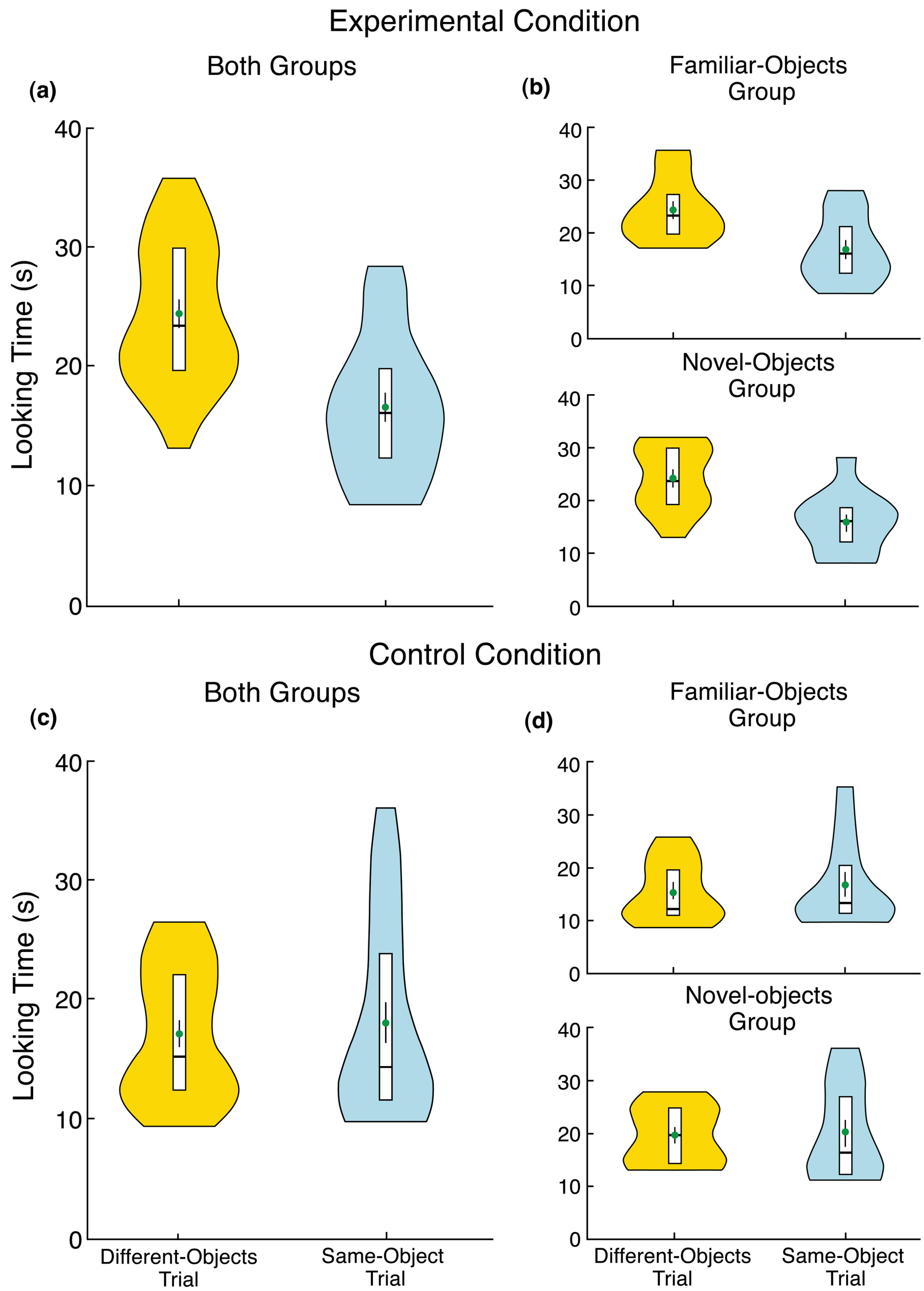

Fig. 7. Violin plots showing infants' raw looking times during the different-objects and same-object test trials in Experiment 2, in the experimental condition (**a**) and its familiar- and novel-objects groups (**b**), and in the control condition (**c**) and its familiar- and novel-objects groups (**d**). In each condition, similar results were expected in the two groups. Dots represent means, and error bars represent standard errors. The width of the shaded area represents the proportion of looking times observed at each value, smoothed by a kernel density estimator. Overlaid on each violin plot is a boxplot with a box ranging from the 25th to the 75th percentile, and a line drawn at the median.